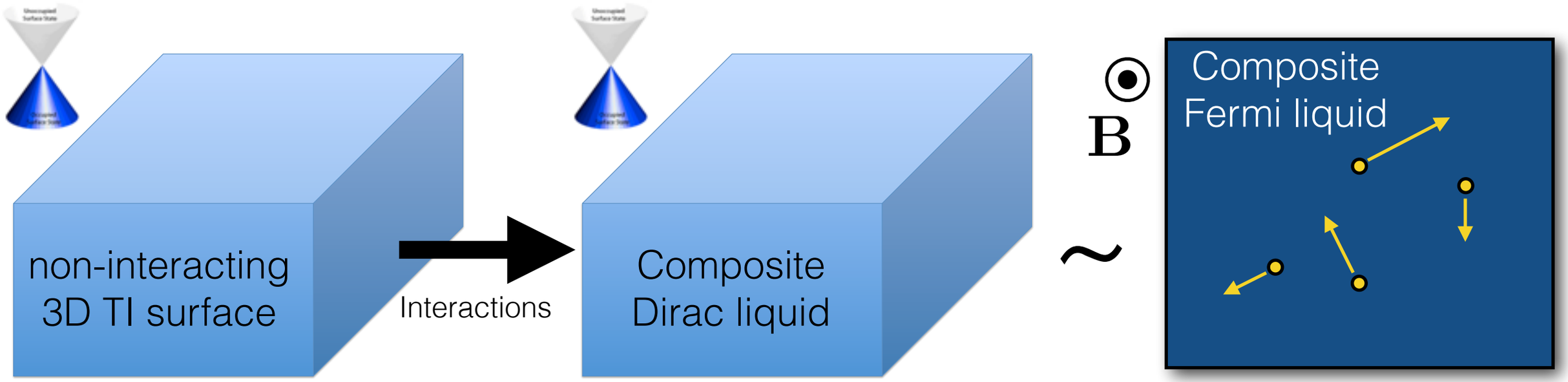
Composite Dirac liquids



Jason Alicea, Caltech

David Mross, Andrew Essin, & JA,
Physical Review X **5**, 011011 (2015)

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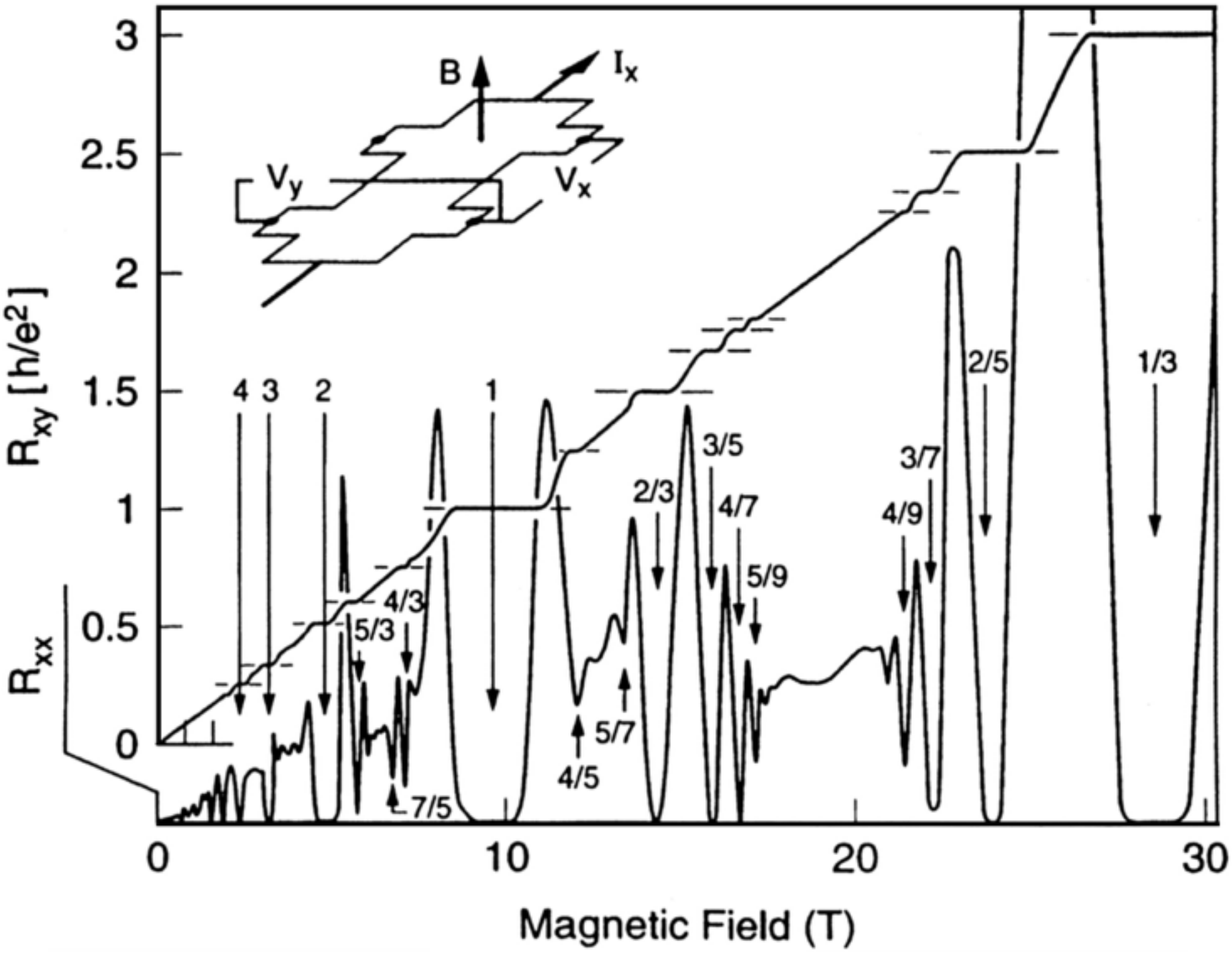
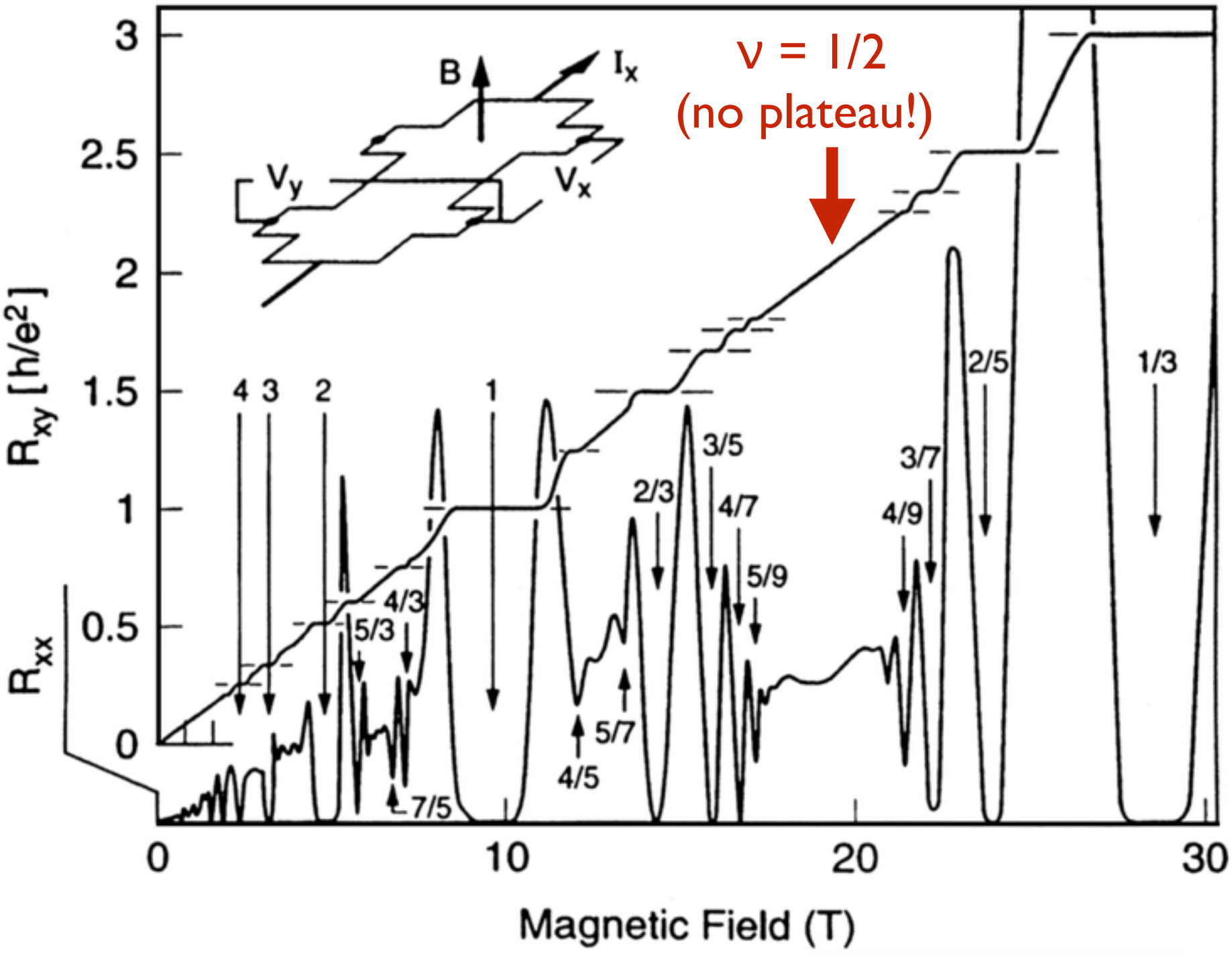
IQIM
INSTITUTE FOR QUANTUM INFORMATION AND MATTER

BURKE
INSTITUTE

ALFRED P. SLOAN FOUNDATION 1934



O(100) plateaus observed to date. **How might we most efficiently capture these topological phases?**



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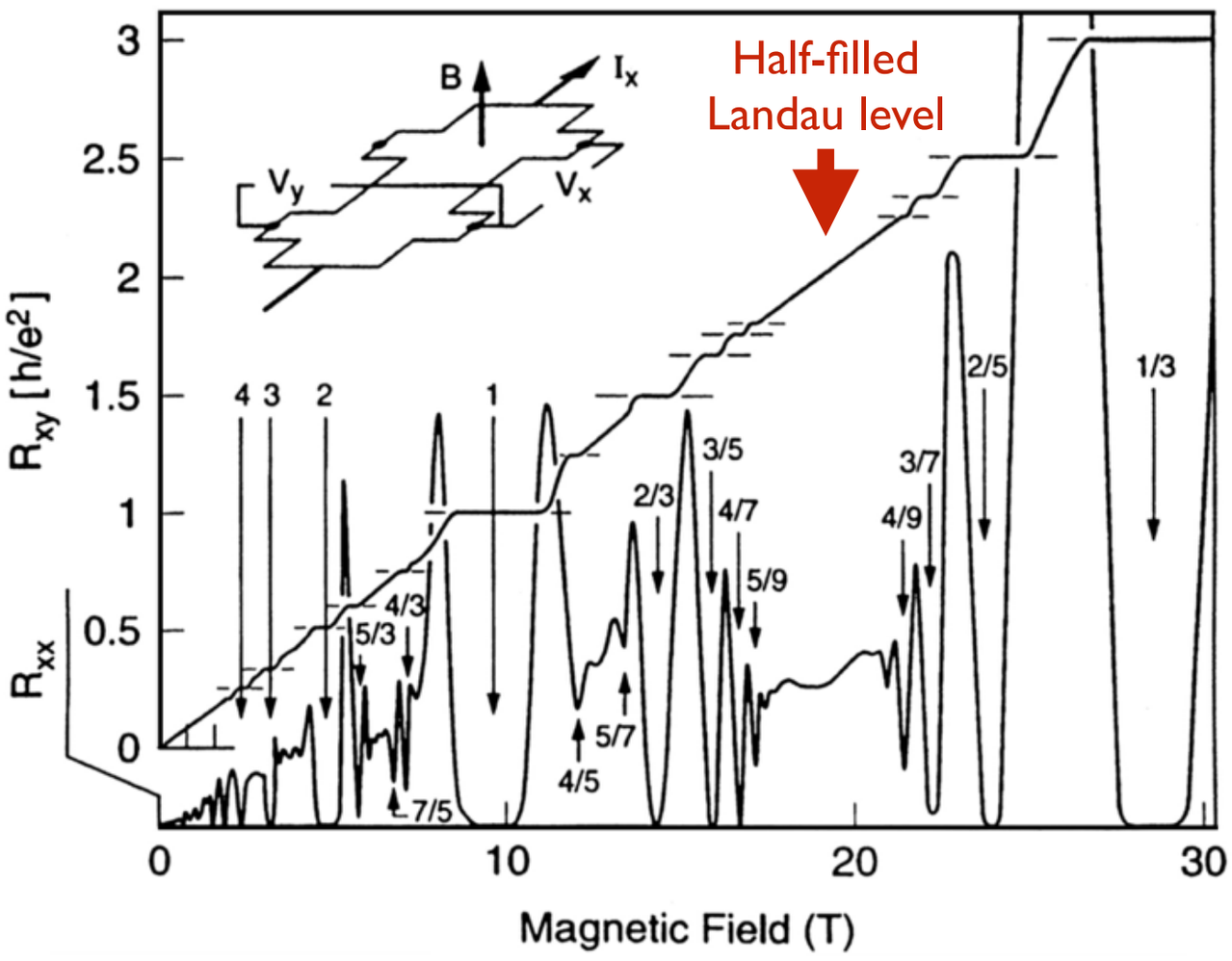
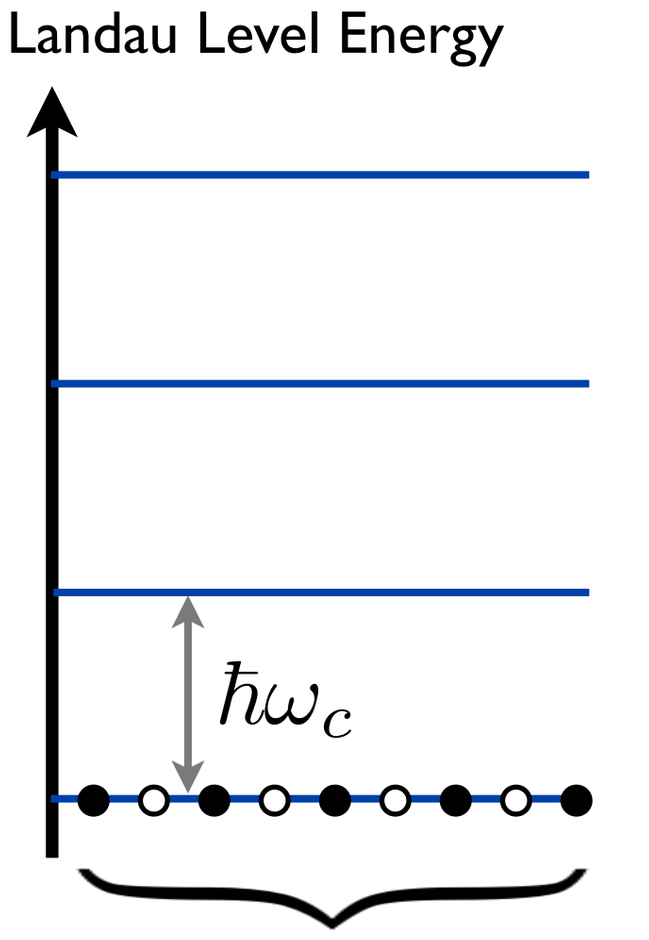
Composite Fermi liquid at ν = 1/2





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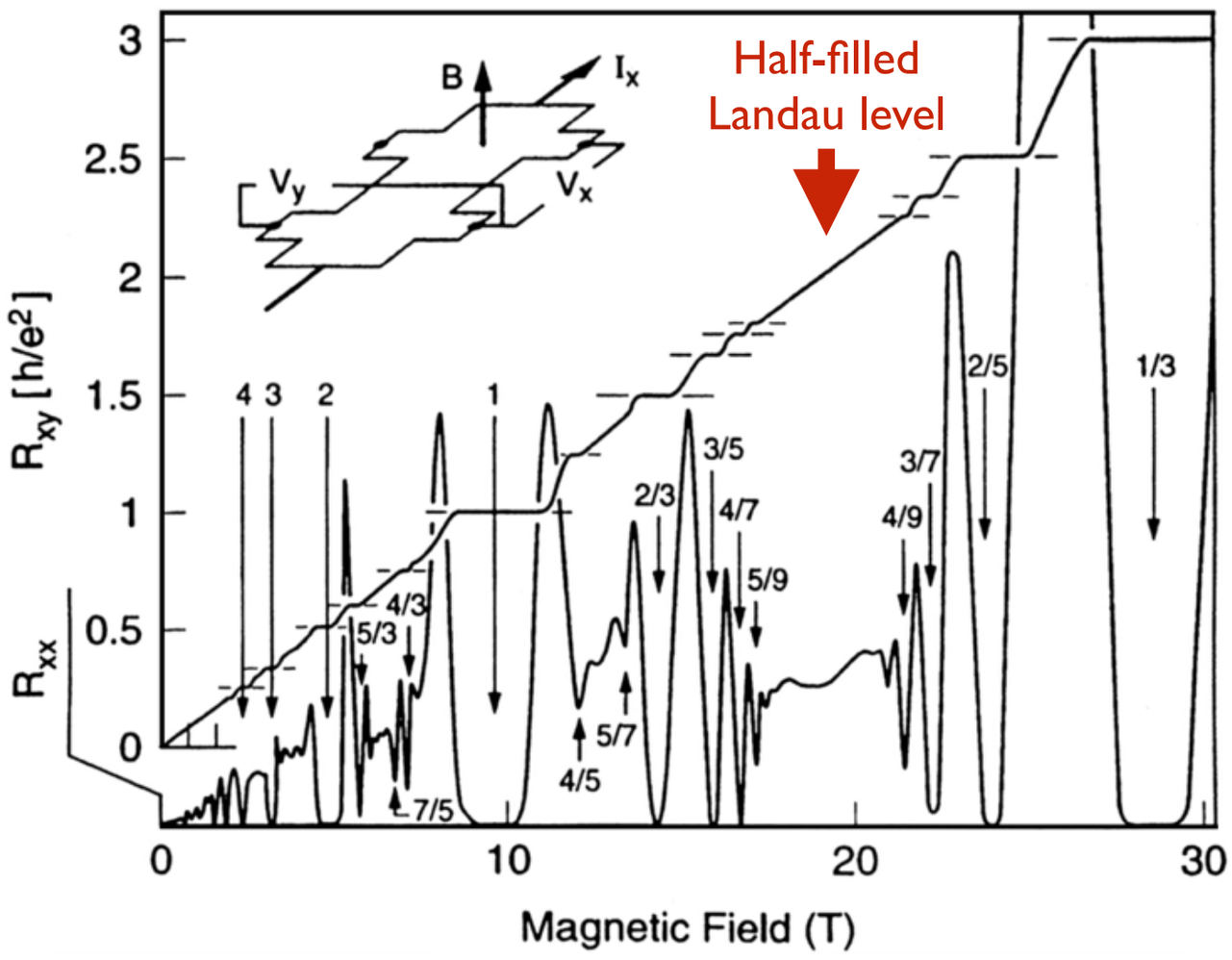

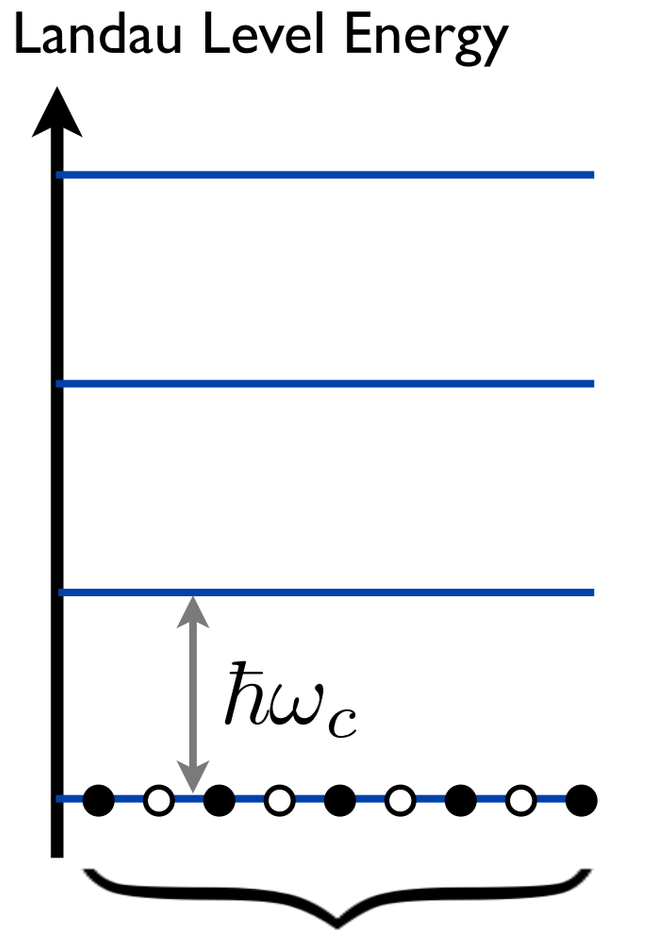

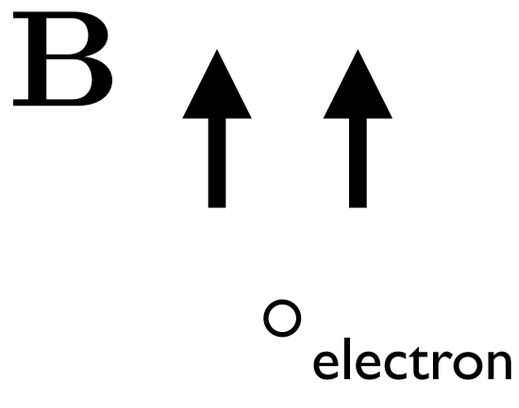

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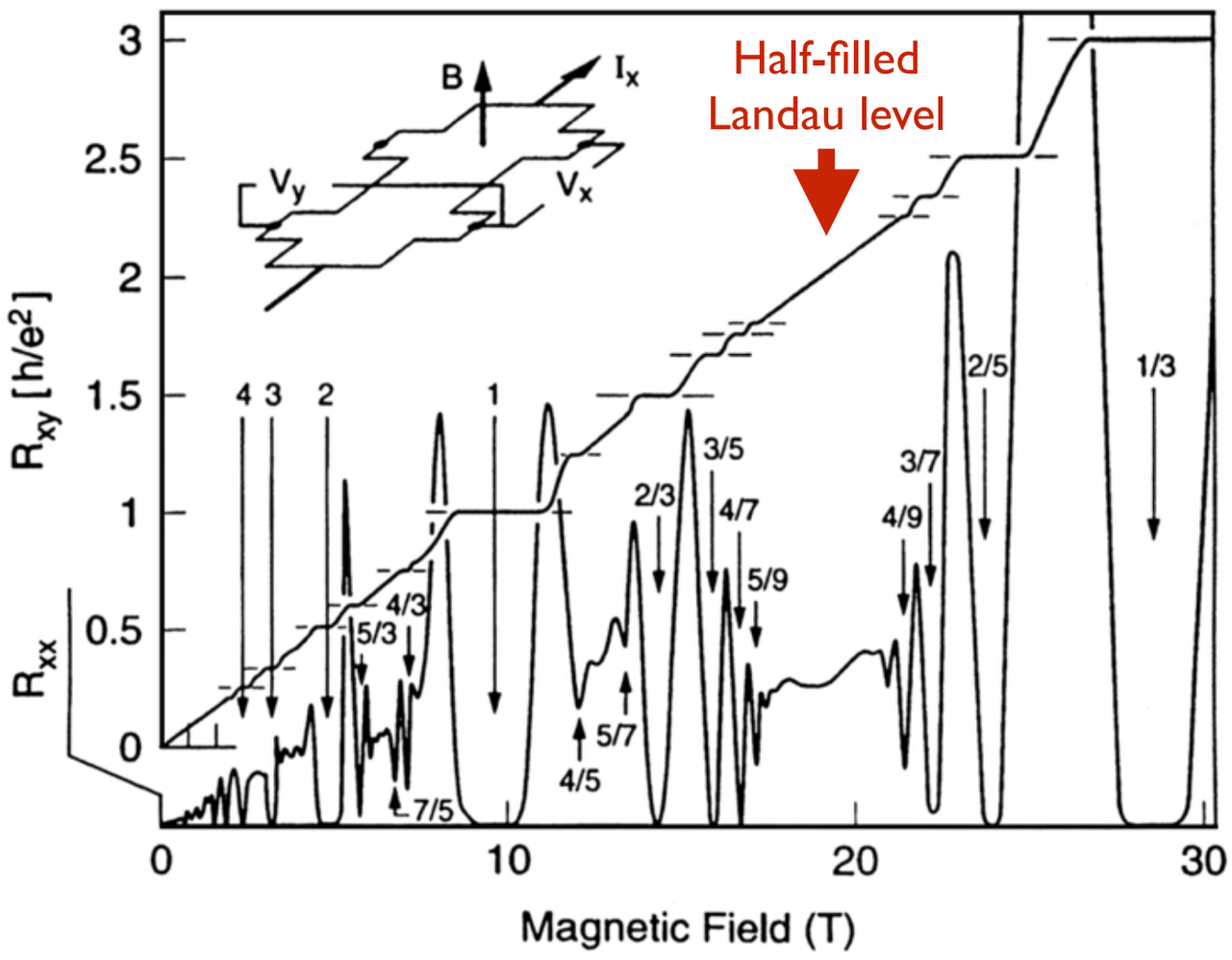

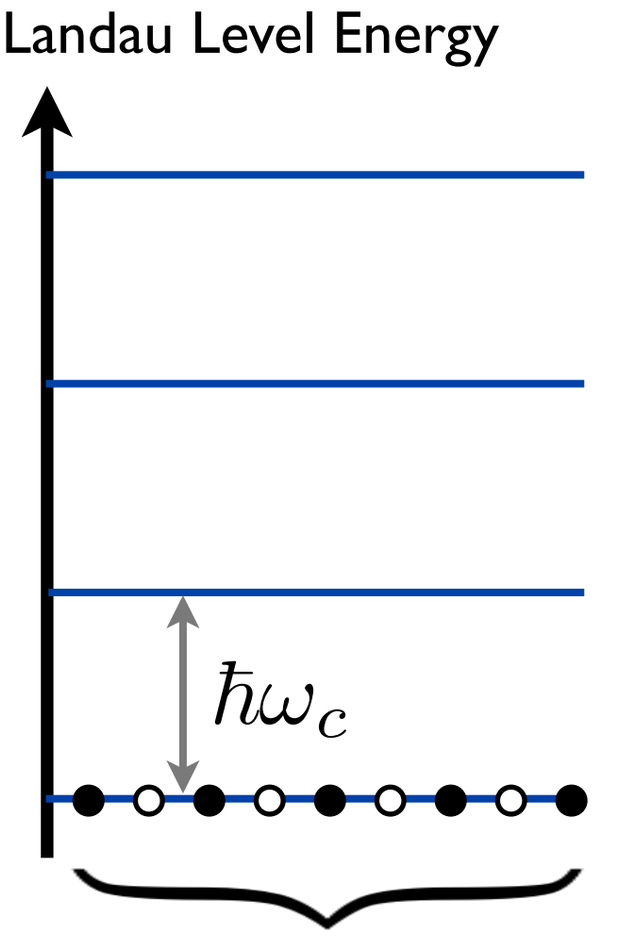

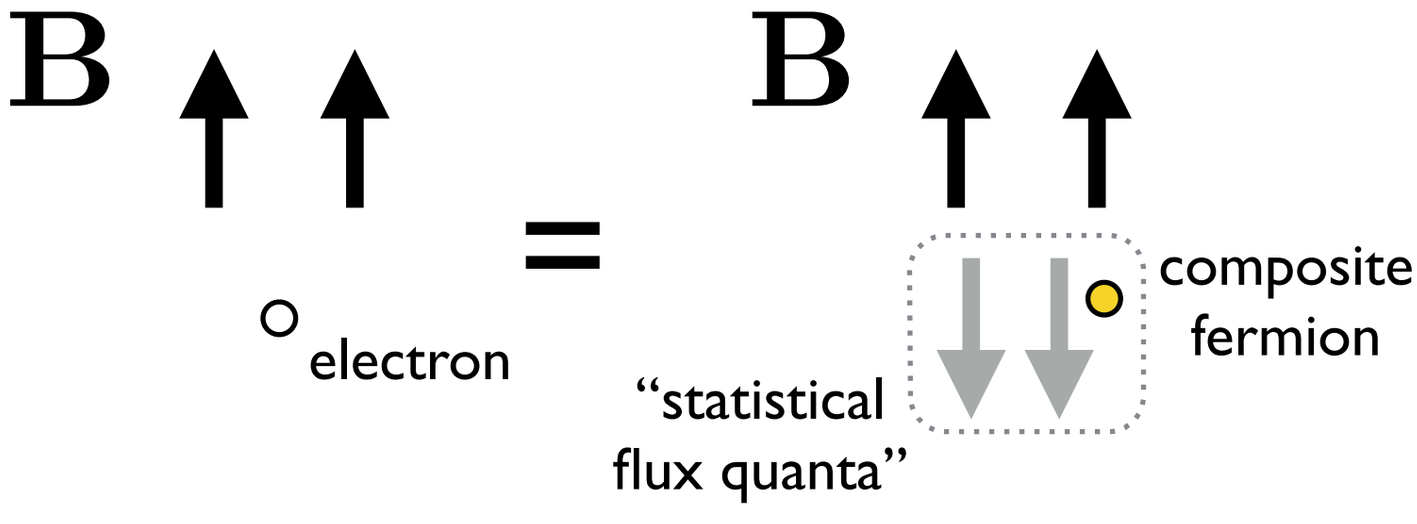

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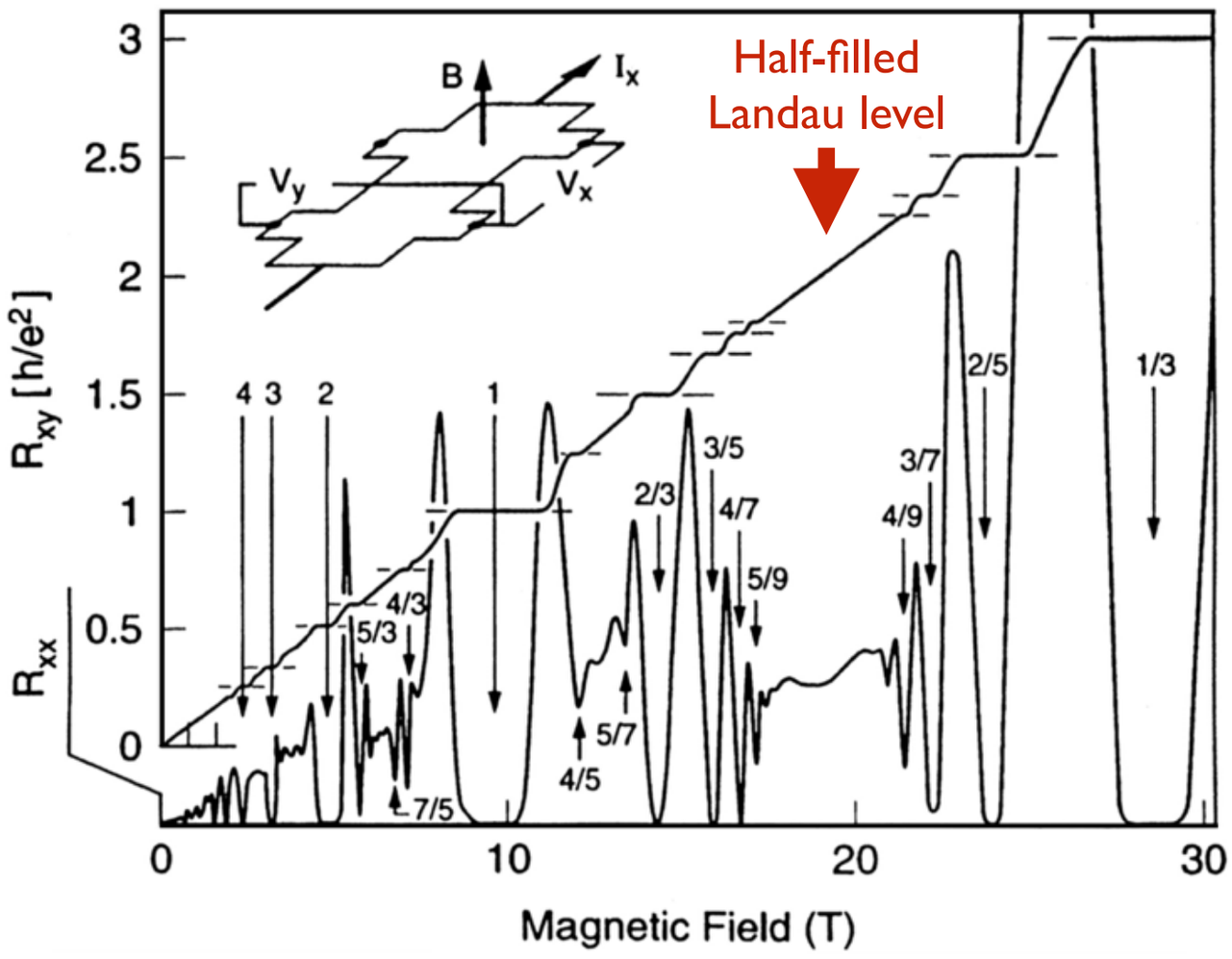

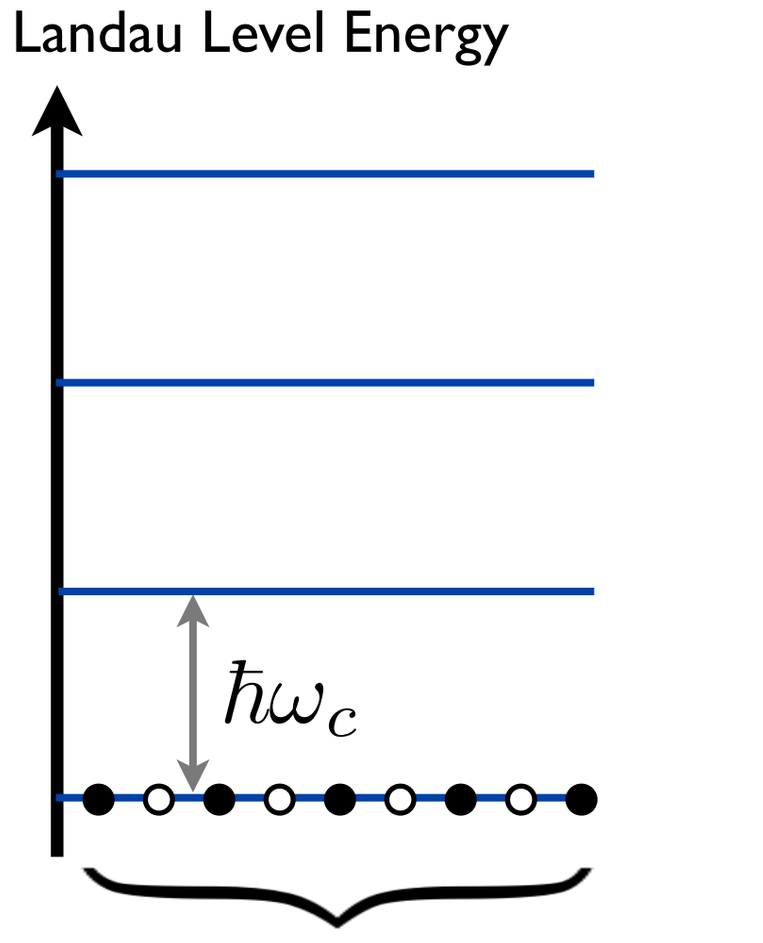

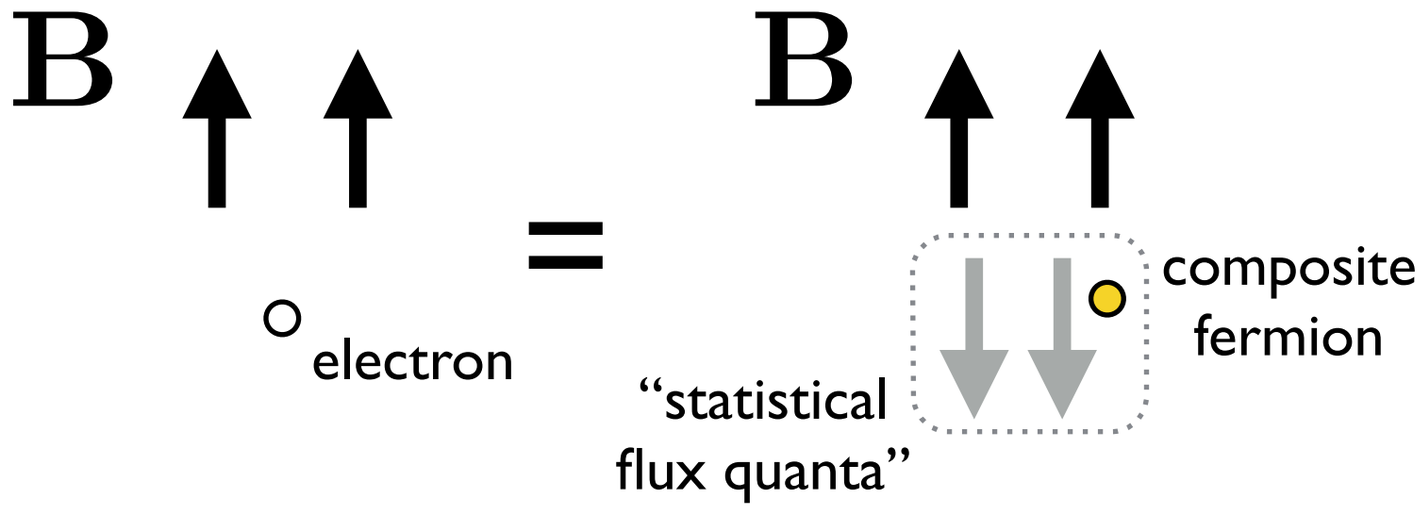

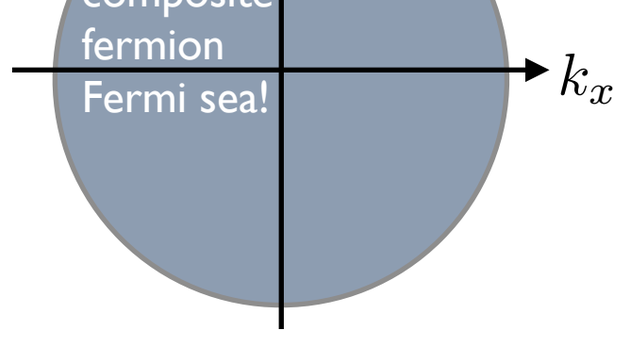

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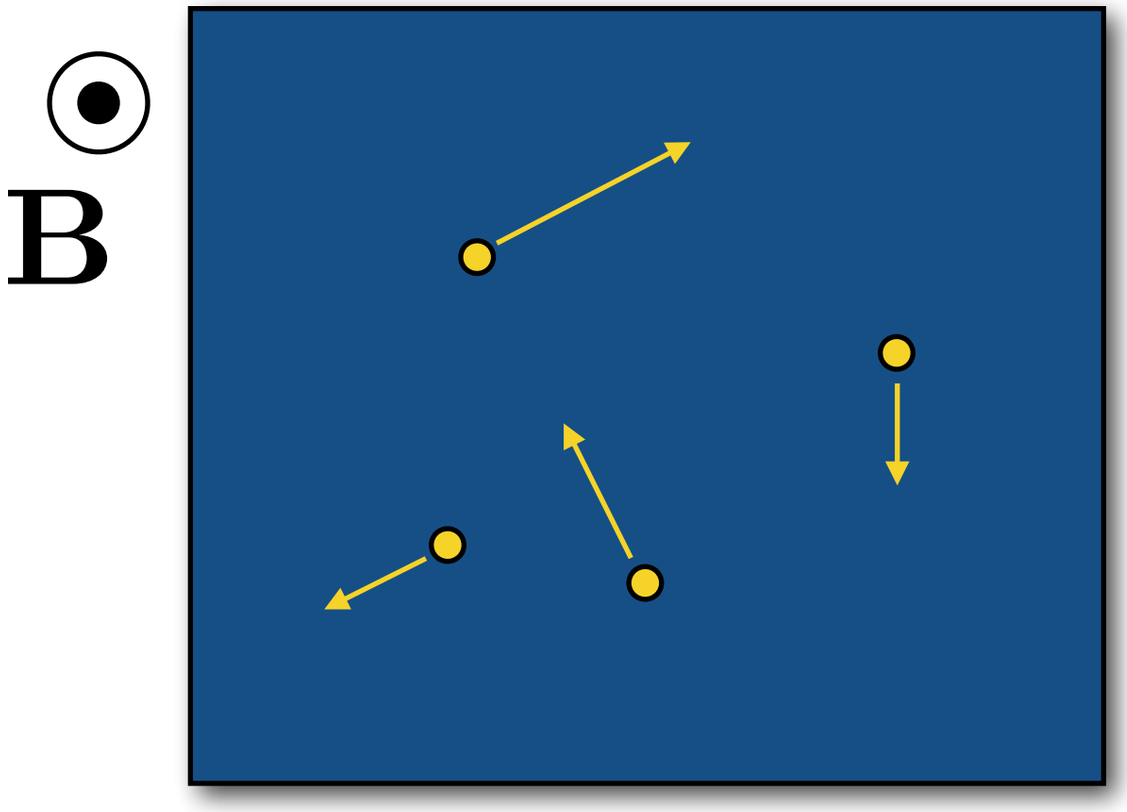

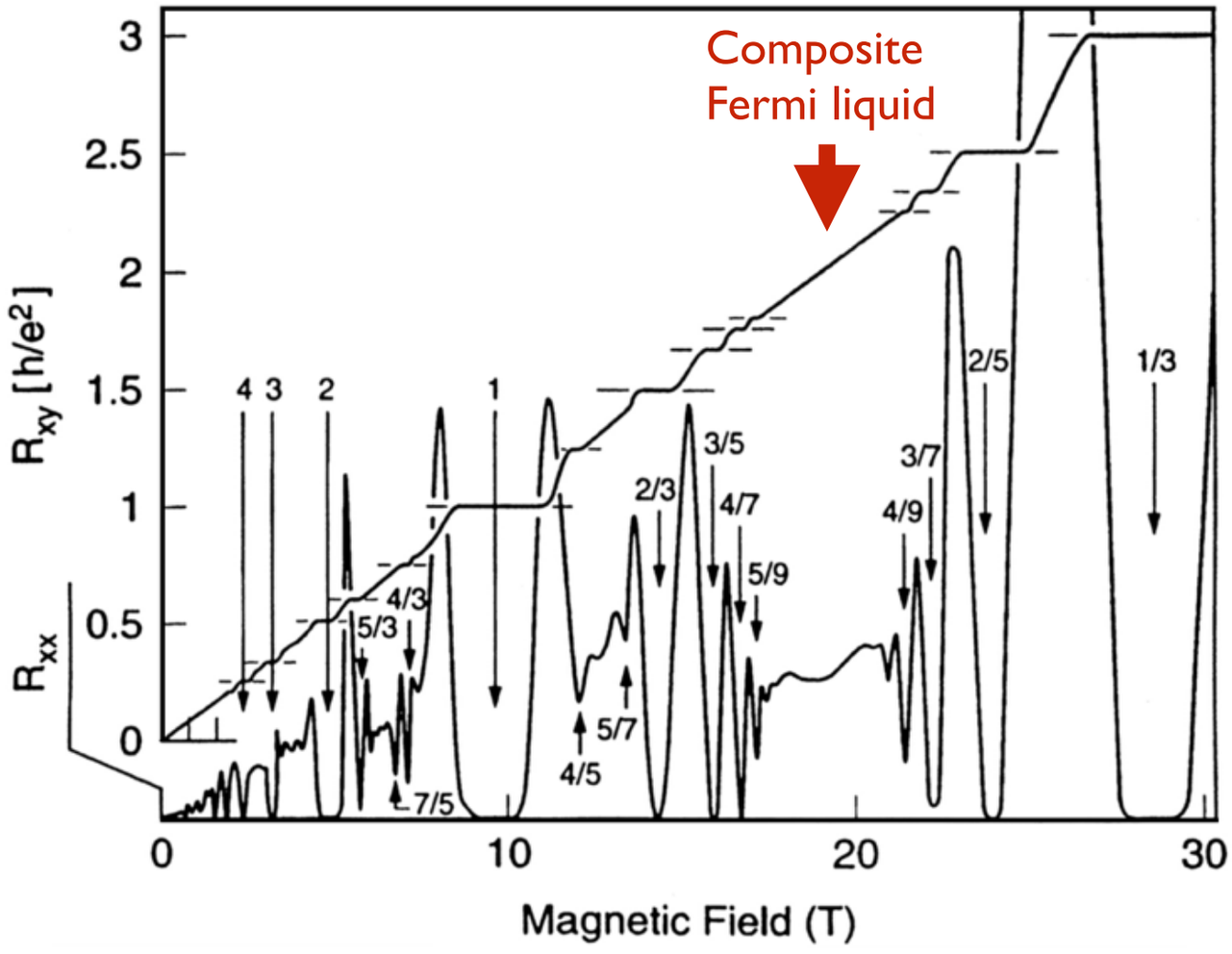

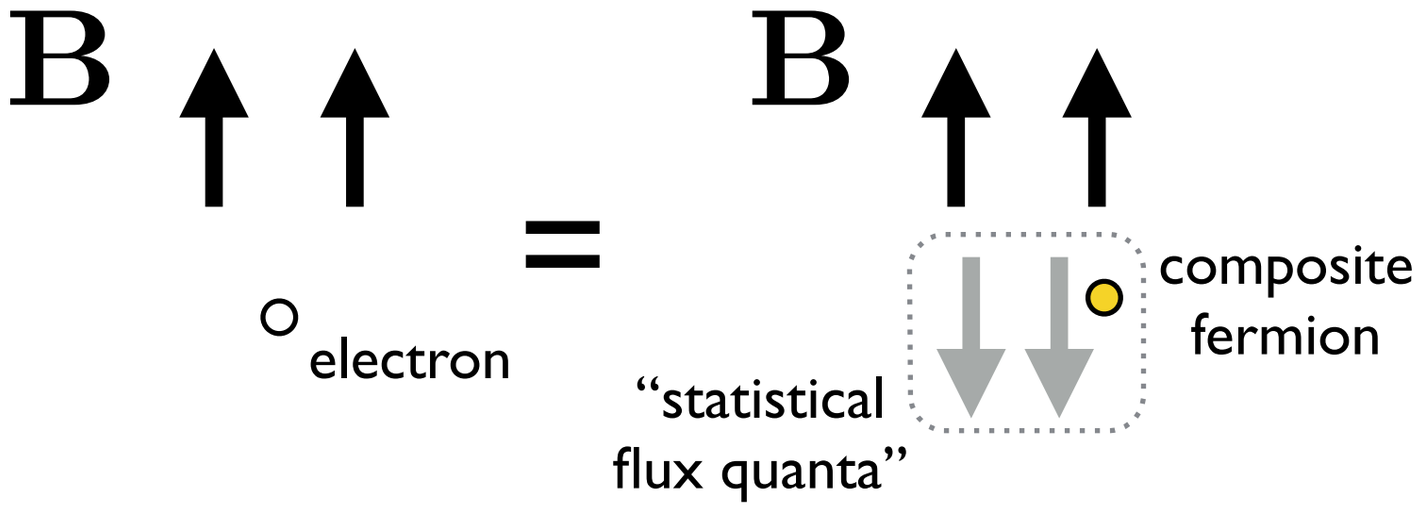

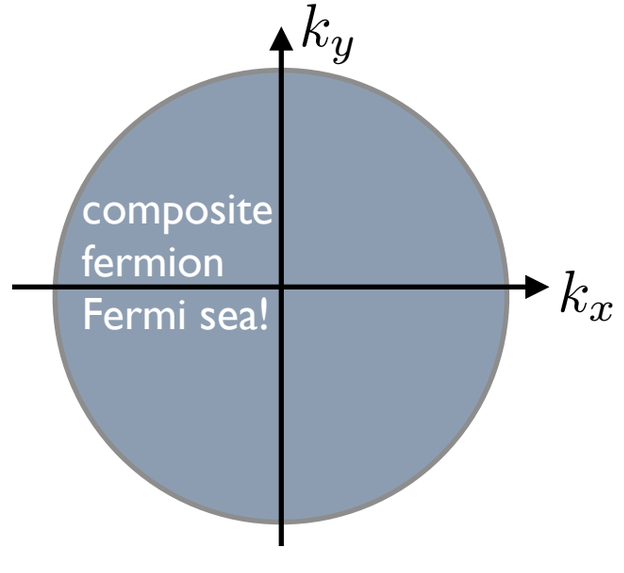

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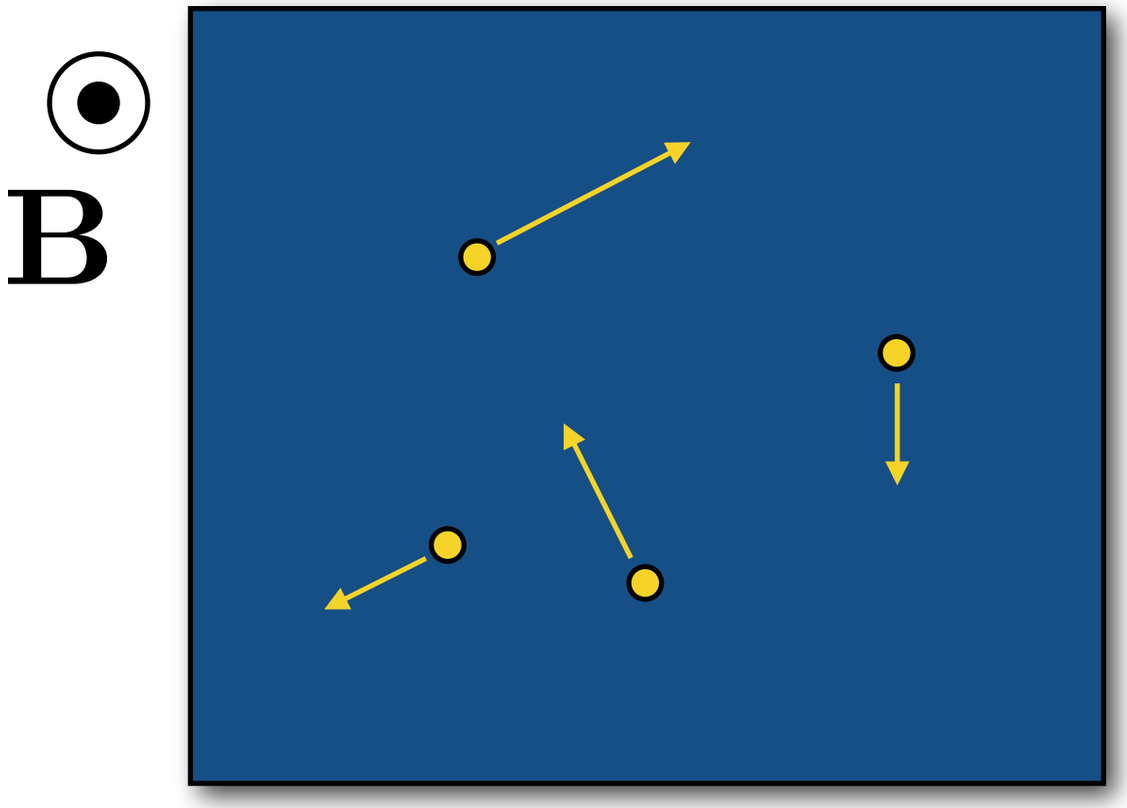

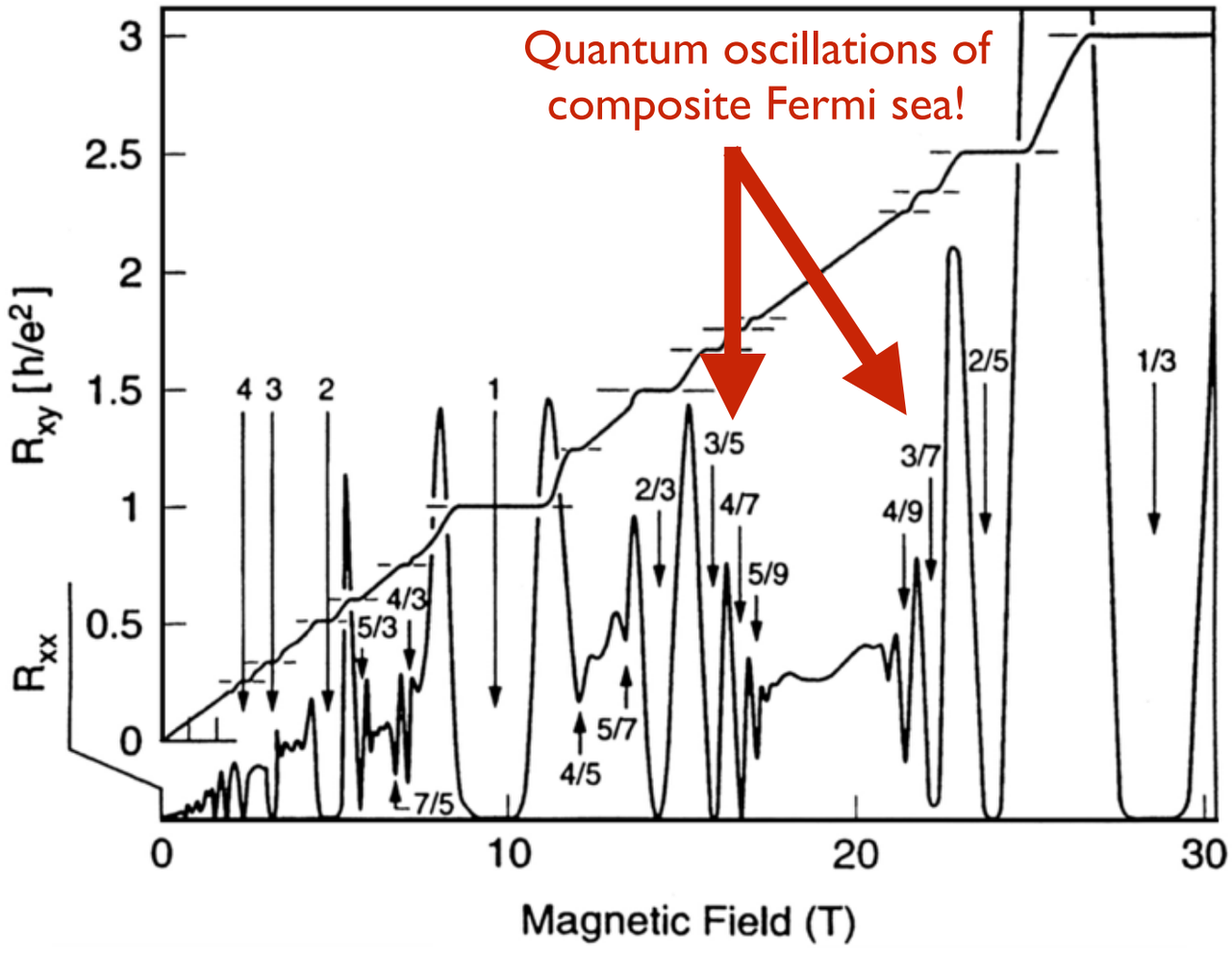

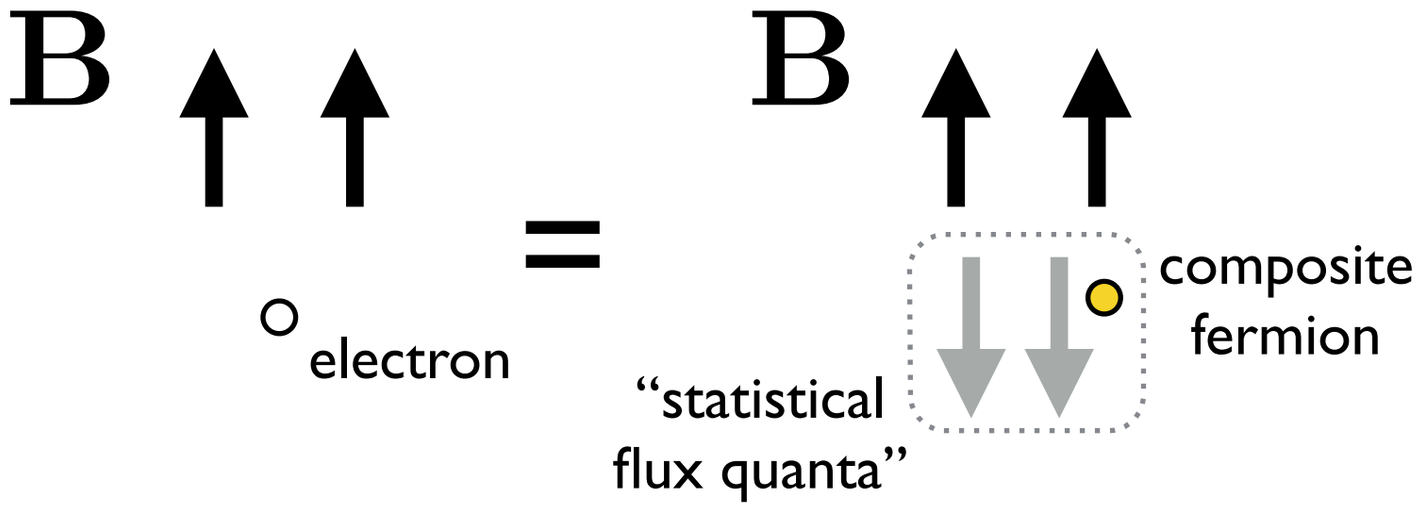

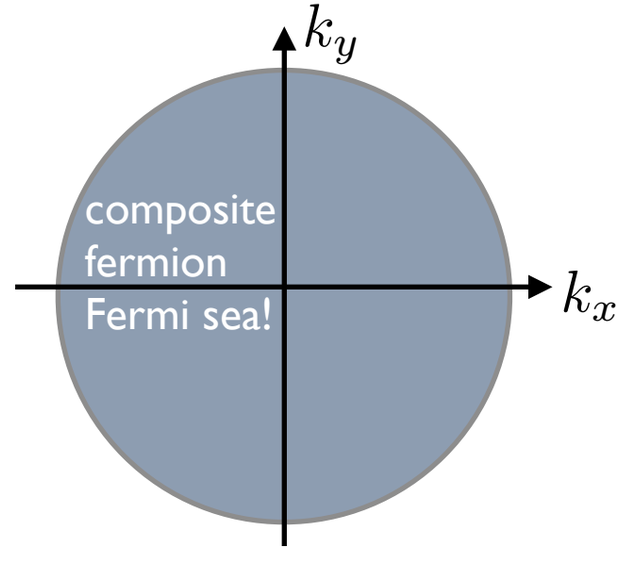

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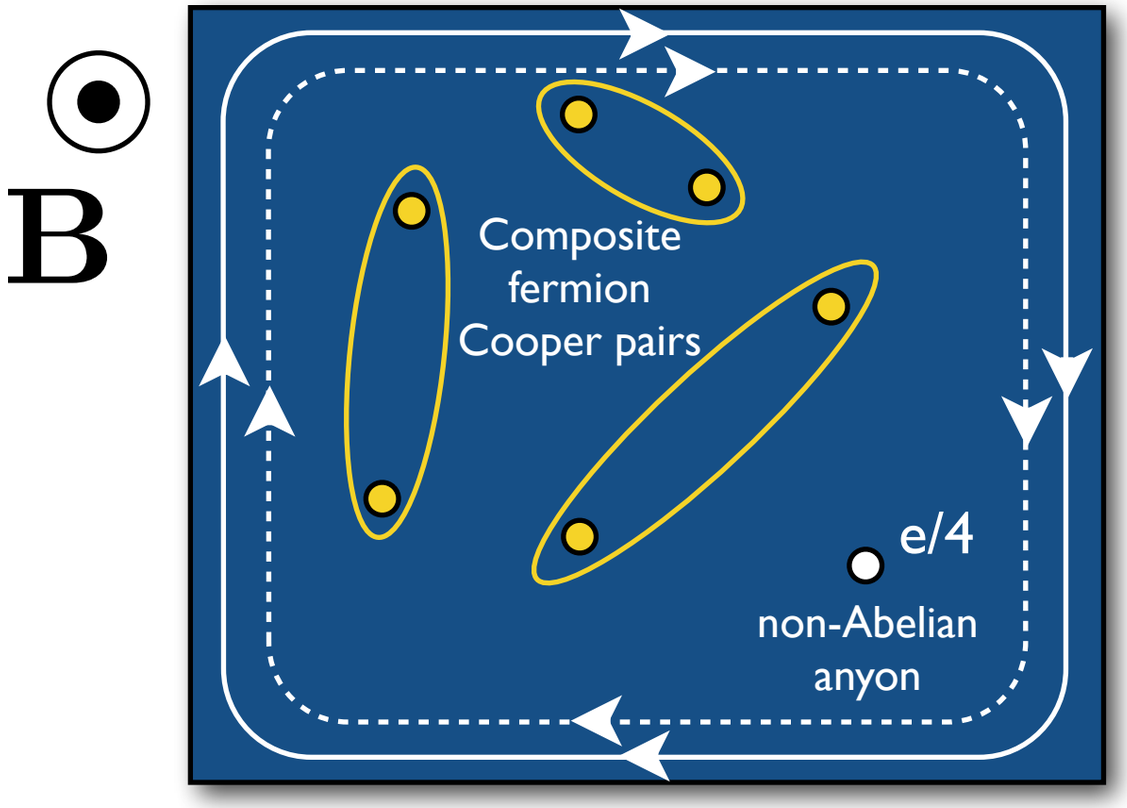
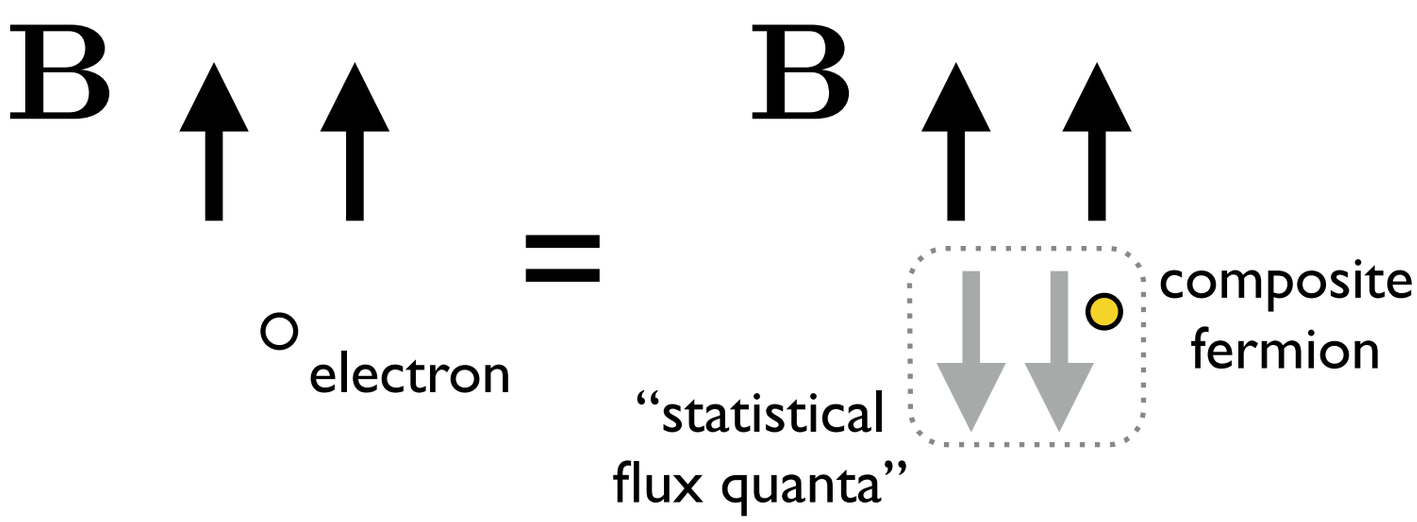
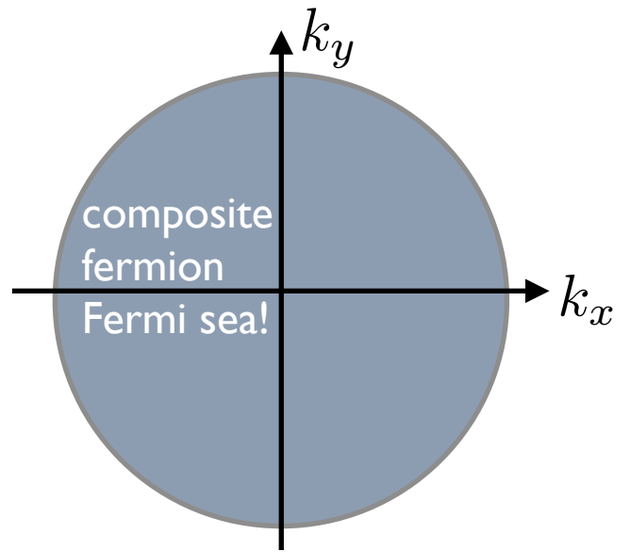


co-propagating Majorana + charge edge modes

Pairing instability of composite Fermi sea yields **non-Abelian** "Moore-Read" fractional quantum Hall state!





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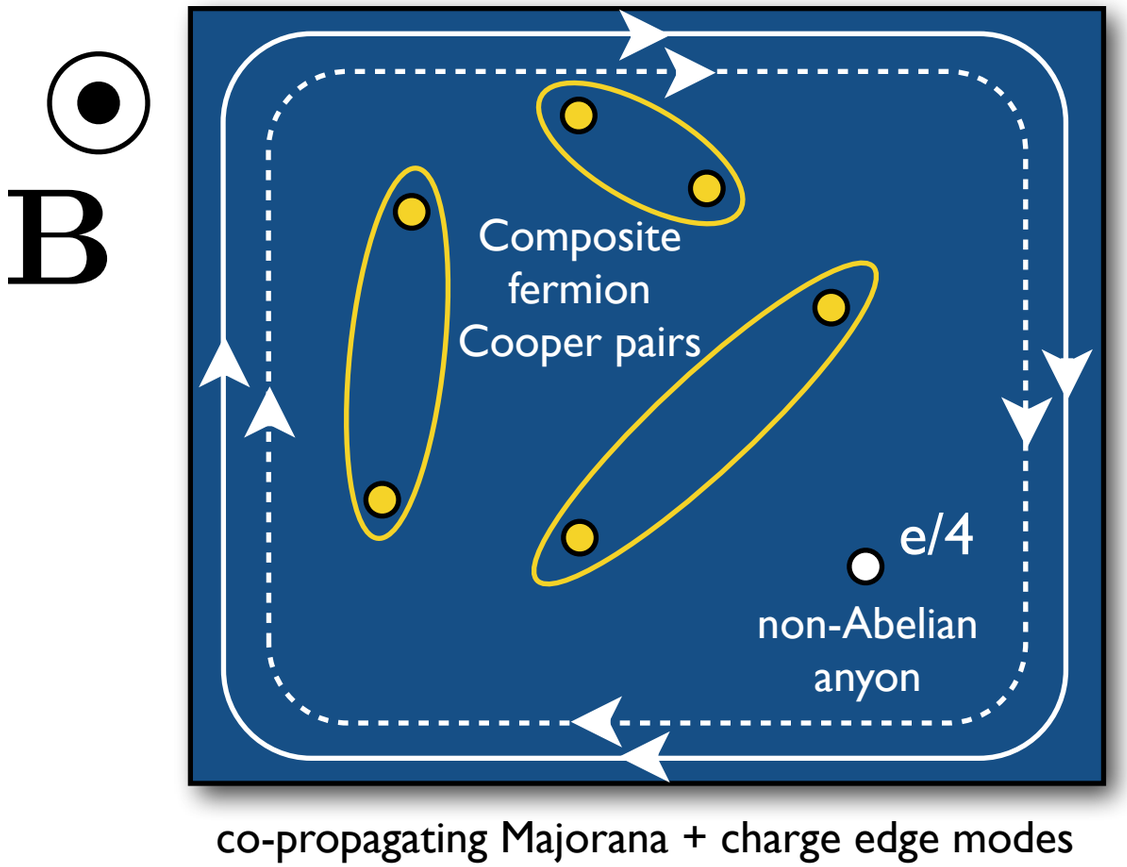

co-propagating Majorana + charge edge modes

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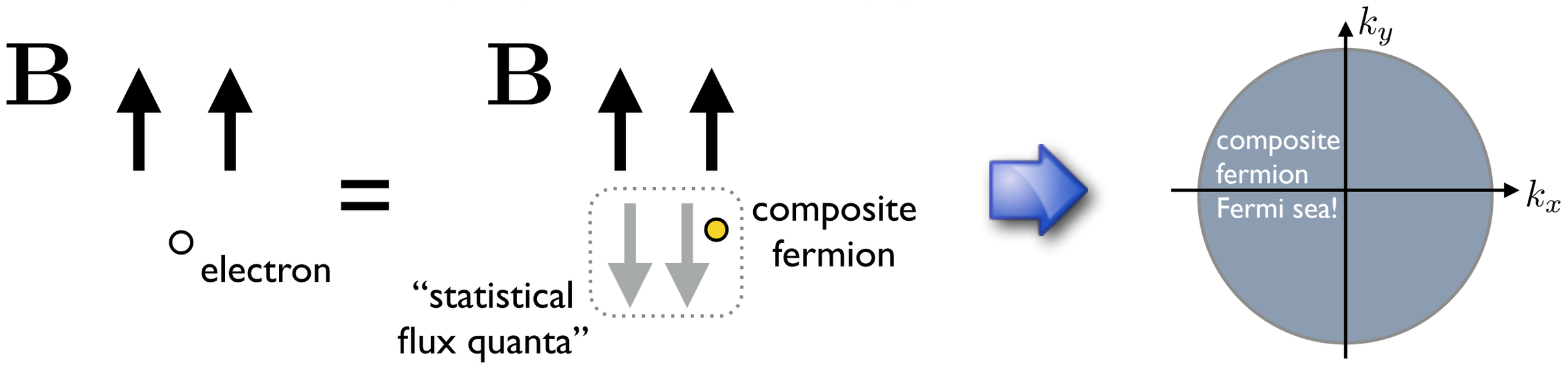
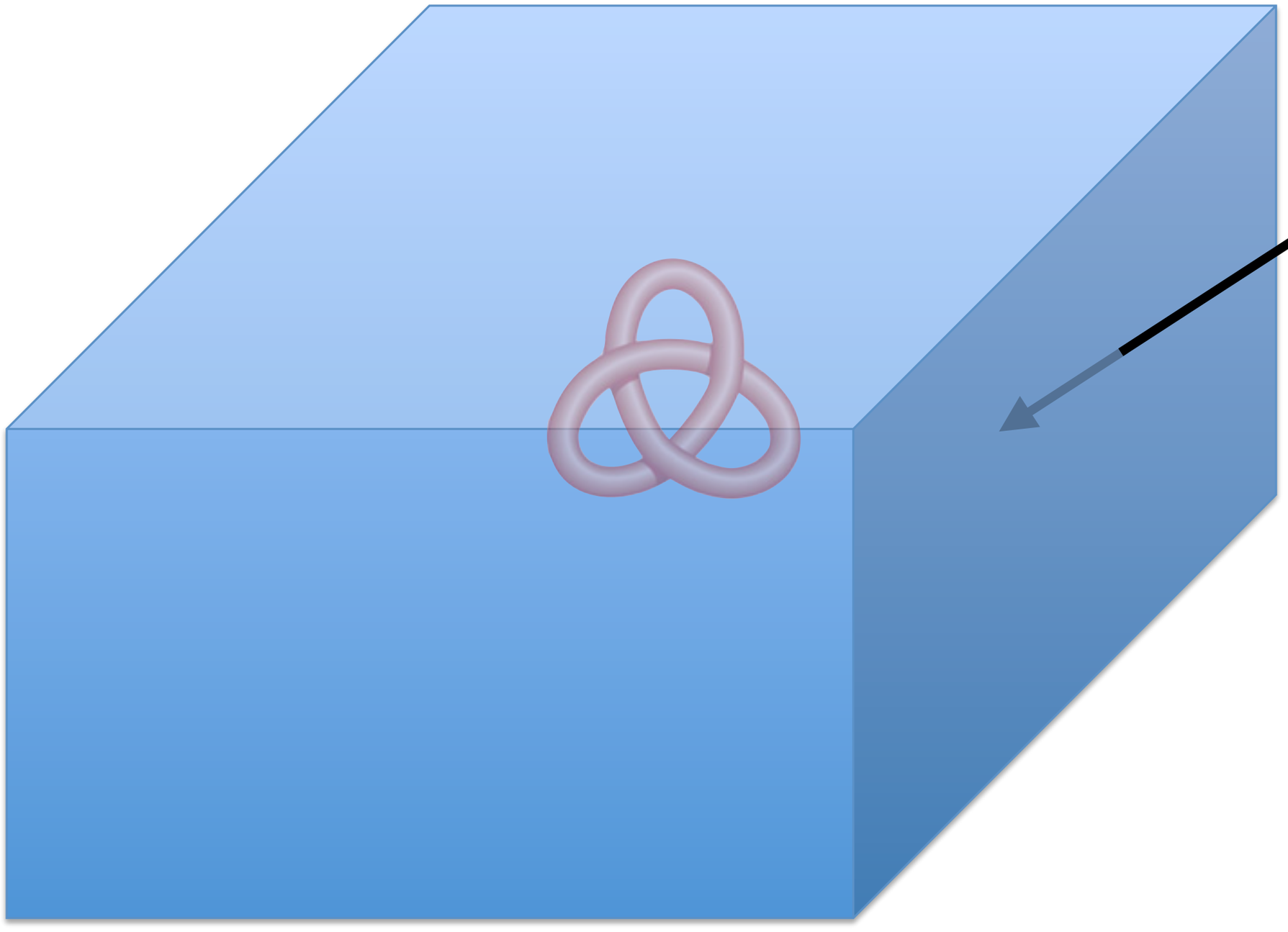
Moral: emergent "metals" are interesting **and** provide efficient way of capturing exotic topologically ordered gapped phases.



Anomalous 3D TI surface physics

3D topological insulator: protected by **time-reversal, U(1) particle conservation symmetries**



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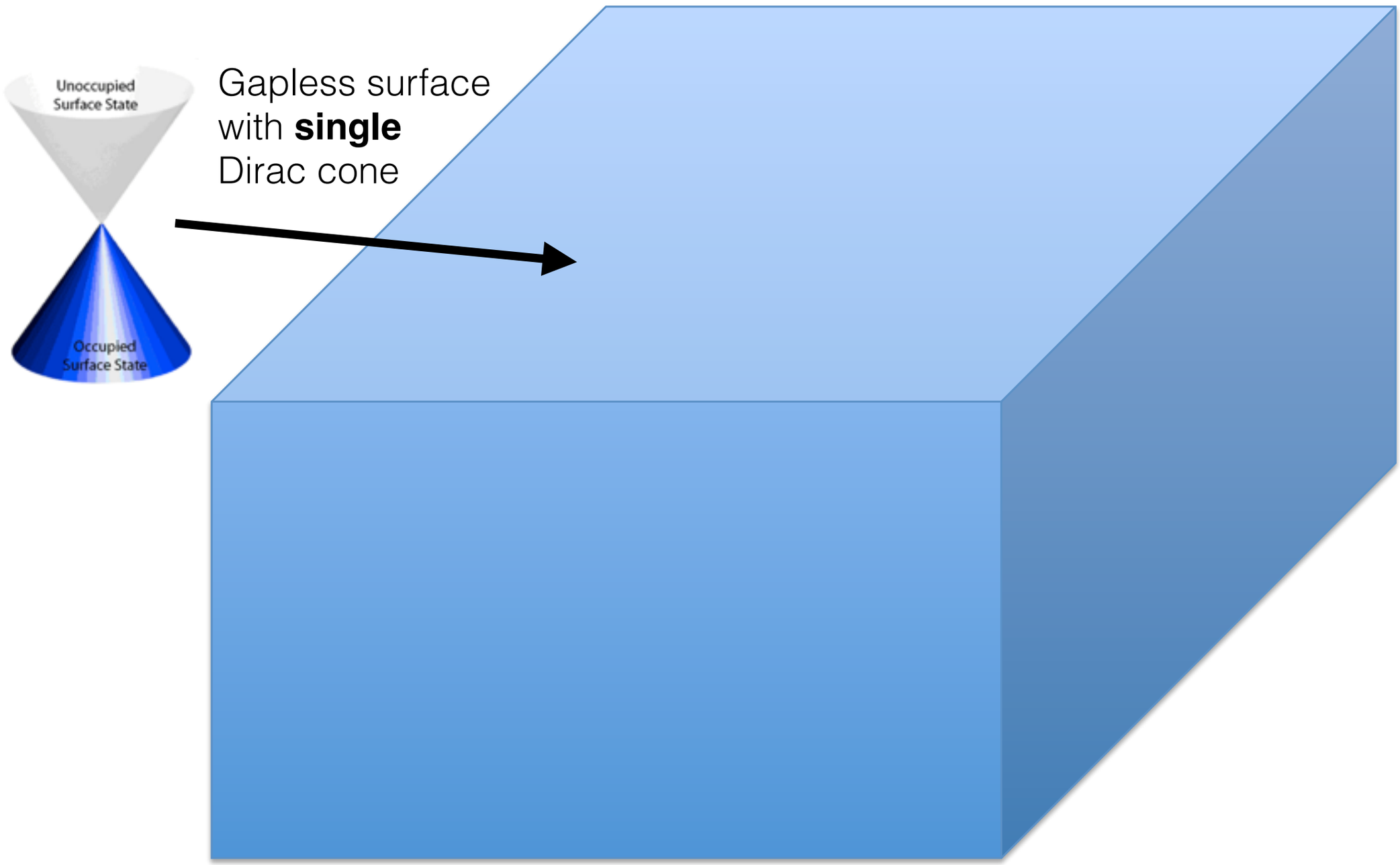

Impossible band structure in strict 2D systems with time-reversal, where only **even** # of Dirac cones can appear.

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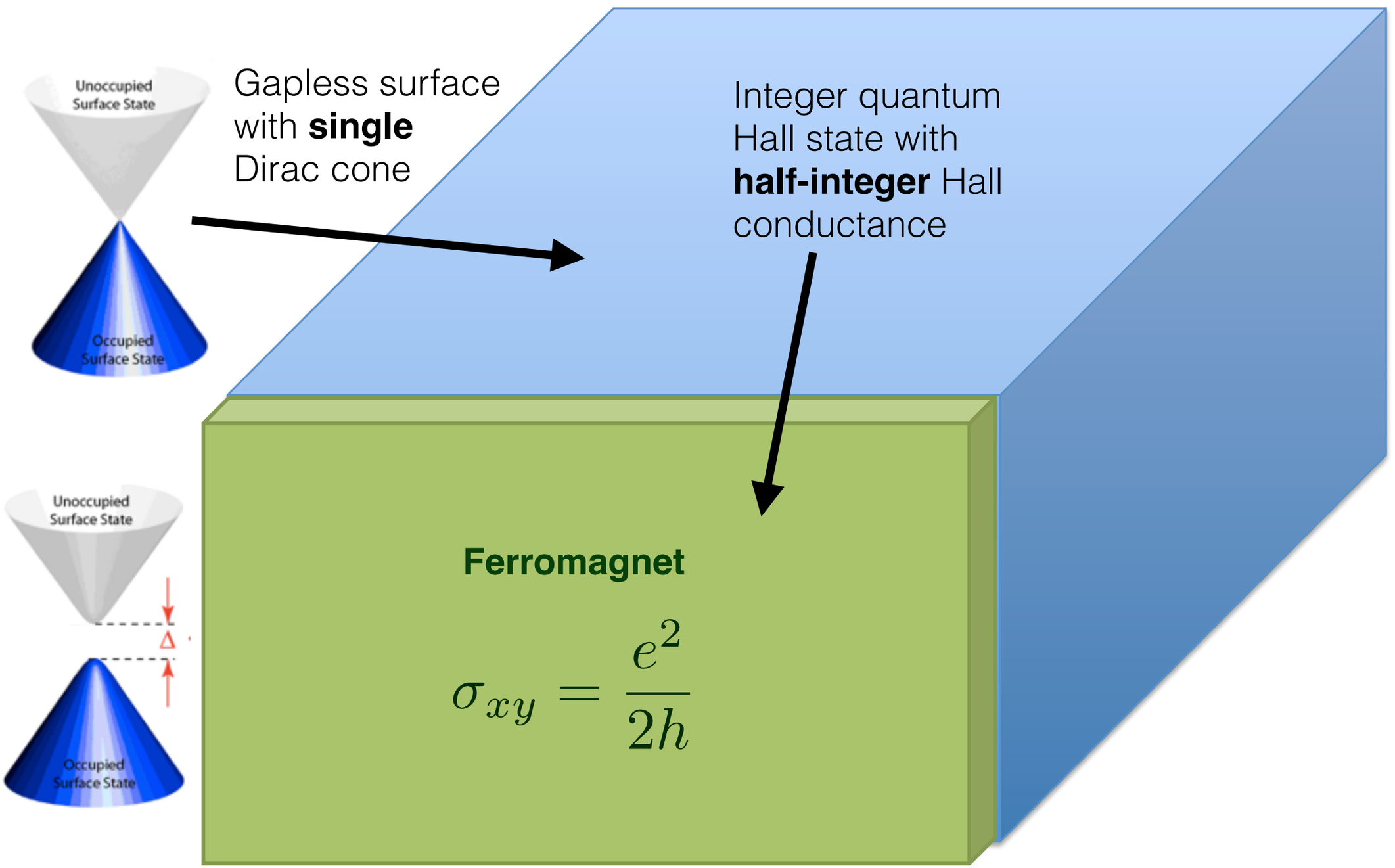

Impossible in strict 2D, since would imply fractionalization, topological order.

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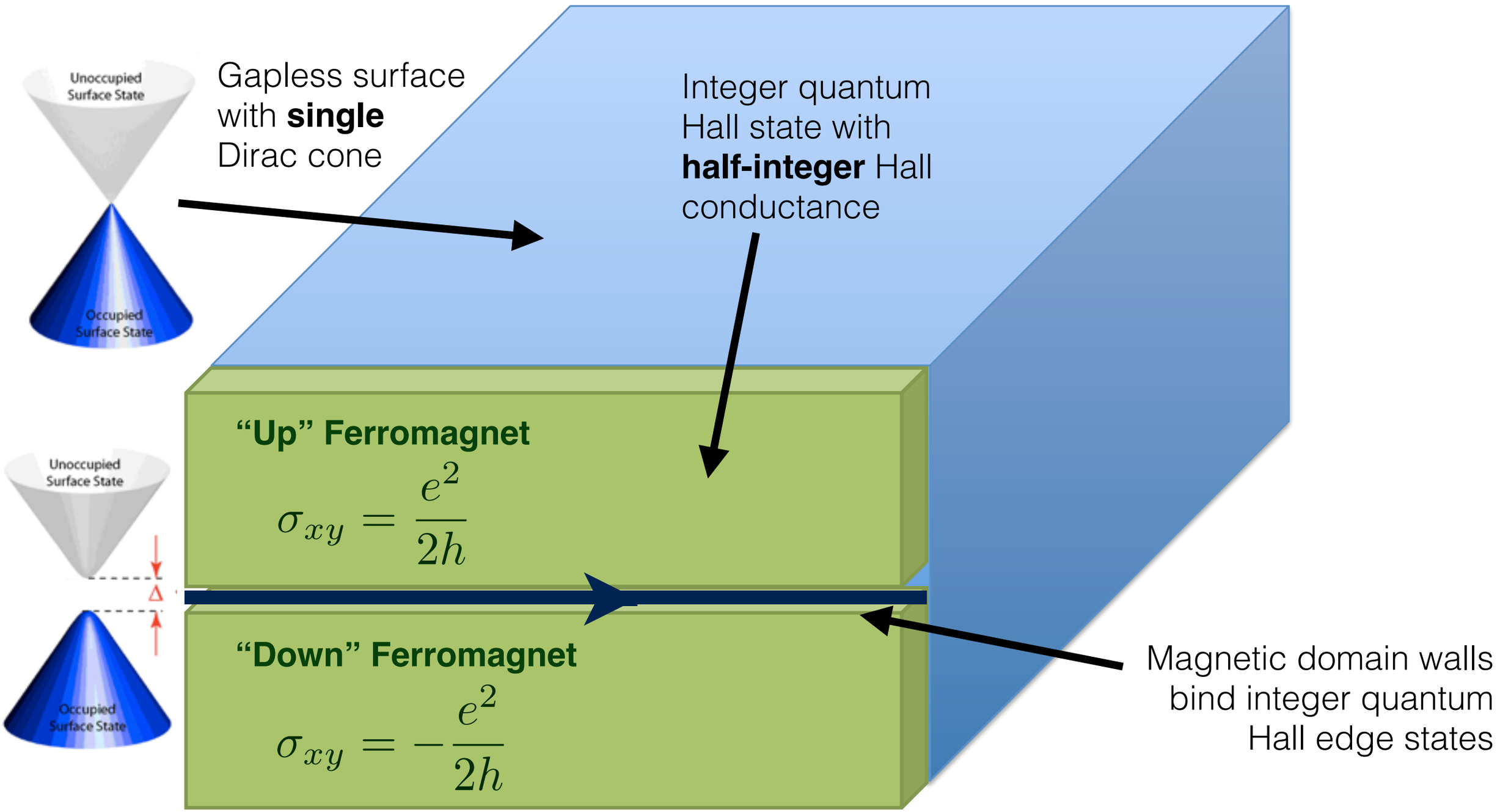

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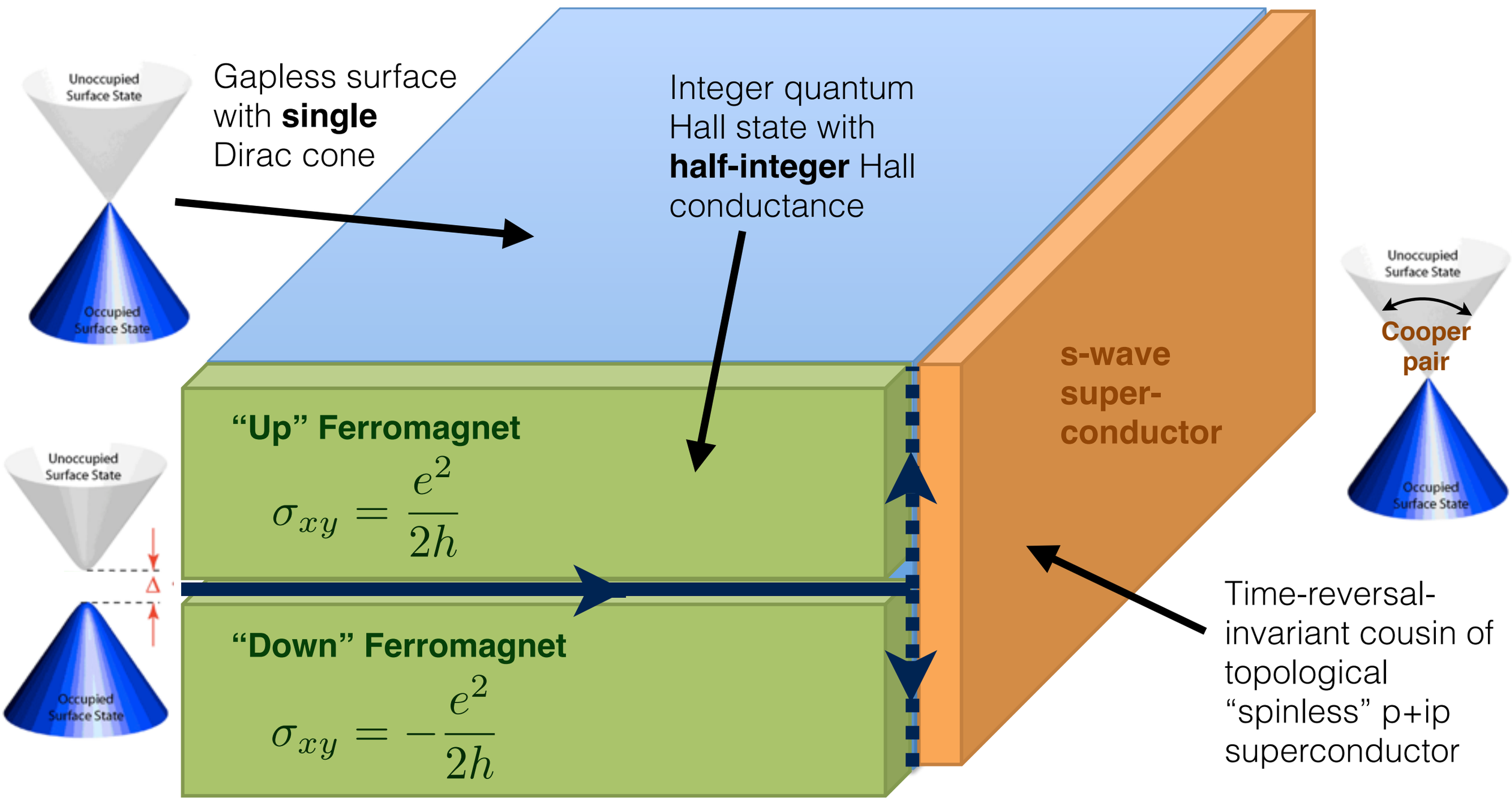

Impossible in strict 2D, since superconductor would always break T.

Without interactions, this is the full story:

-Symmetry implies massless electron Dirac cone
-broken symmetry implies anomalous gapped phases.

Does symmetry imply surface metallicity more generally?

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Does symmetry imply surface metallicity more generally? No!

A Time-Reversal Invariant Topological Phase at the Surface of a 3D Topological Insulator

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Symmetry Enforced Non-Abelian Topological Order at the Surface of a Topological Insulator

Xie Chen,[1] Lukasz Fidkowski,[2] and Ashvin Vishwanath[1,3]

A symmetry-respecting topologically-ordered surface phase of 3d electron topological insulators

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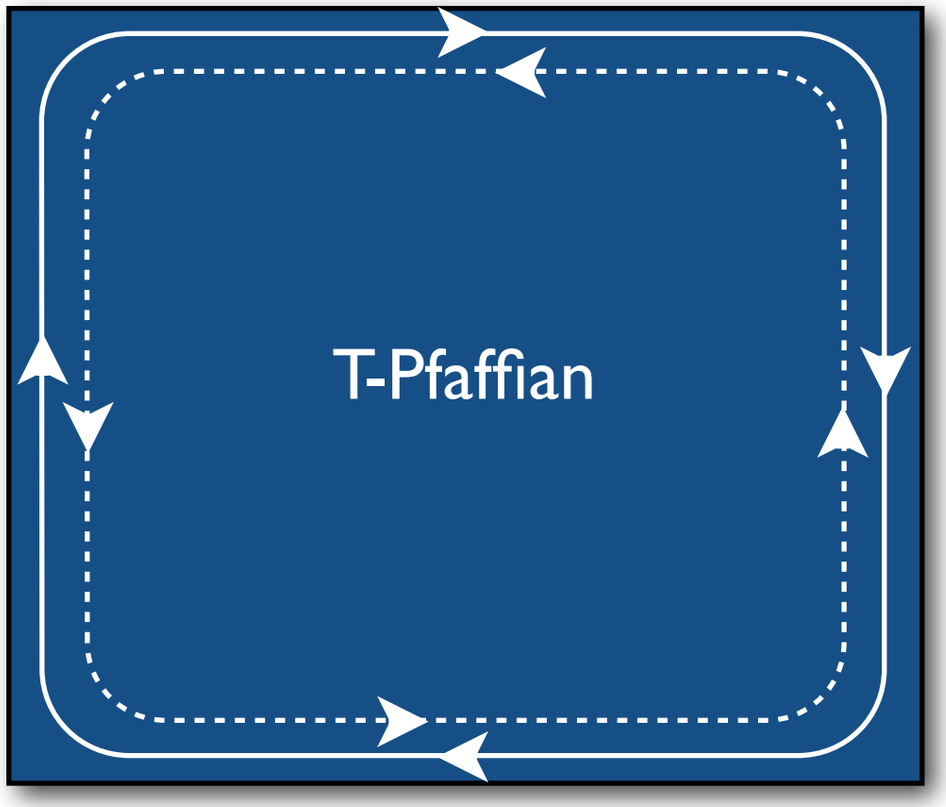
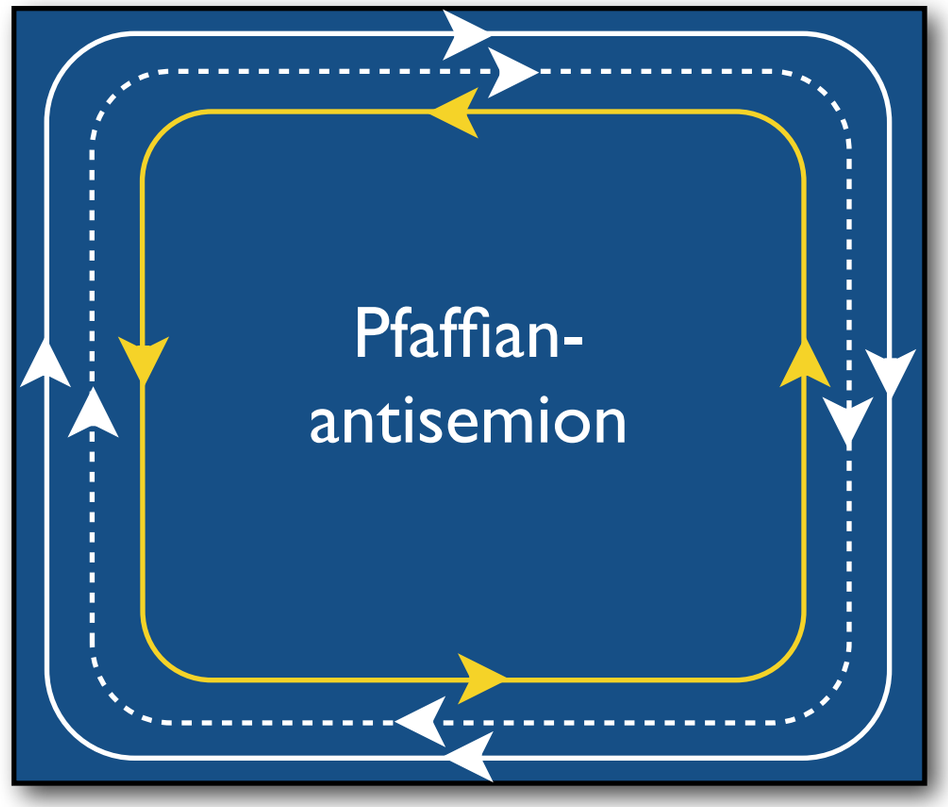
Gapped Symmetry Preserving Surface-State for the Electron Topological Insulator

Chong Wang, Andrew C. Potter, and T. Senthil





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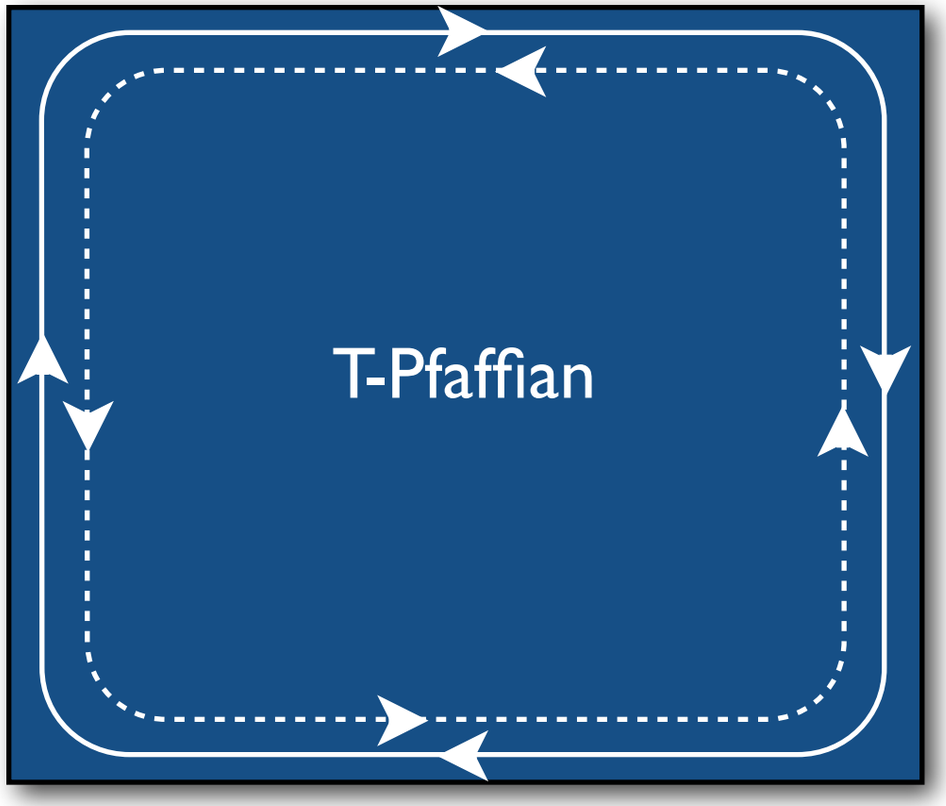
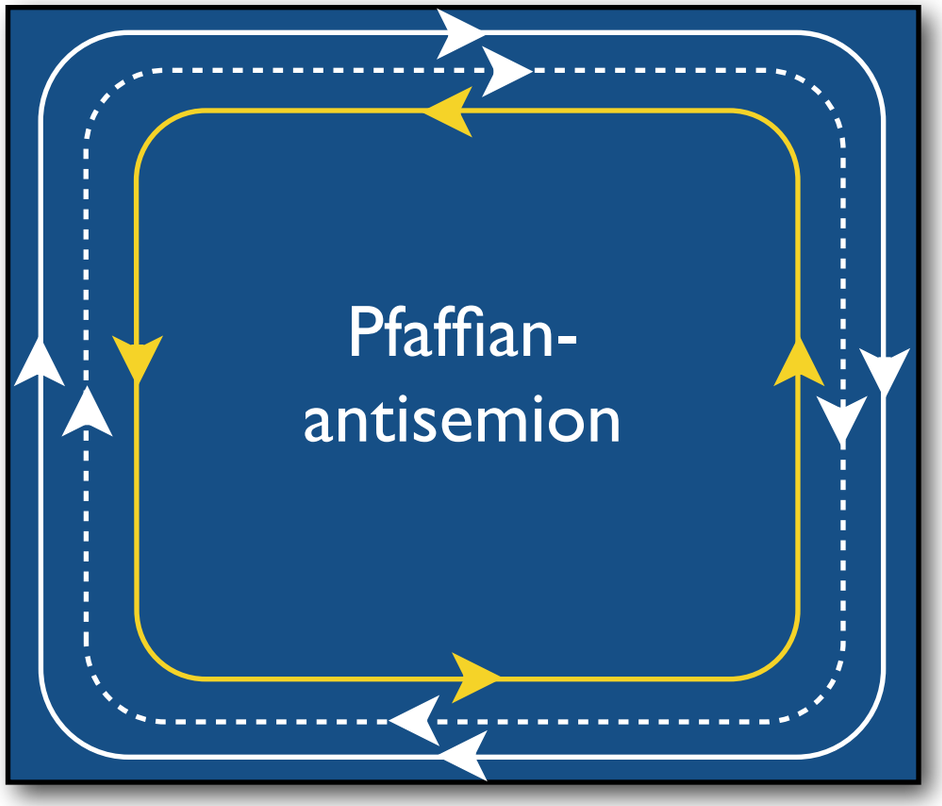


Clearly break time reversal symmetry in 2D, but **not** on surface!



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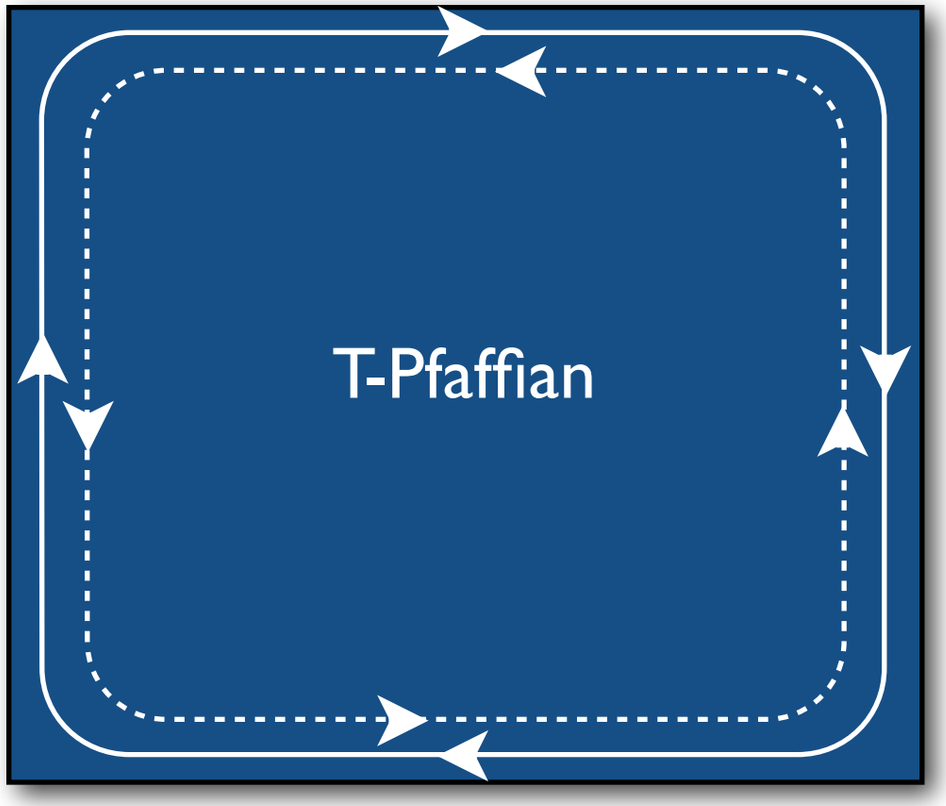

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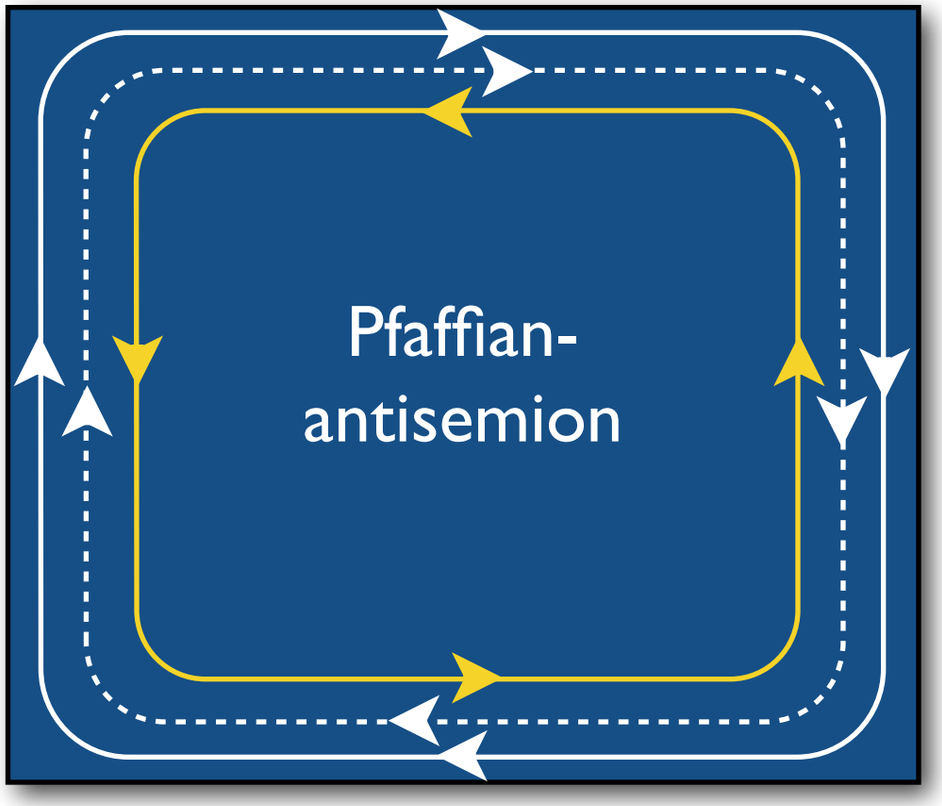
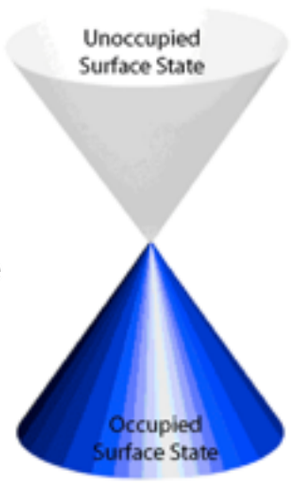


“Composite Dirac liquids”= new correlated gapless surface states that unify these works.

Composite Dirac liquids: phenomenology

non-interacting
3D TI surface



electronic
Dirac cone

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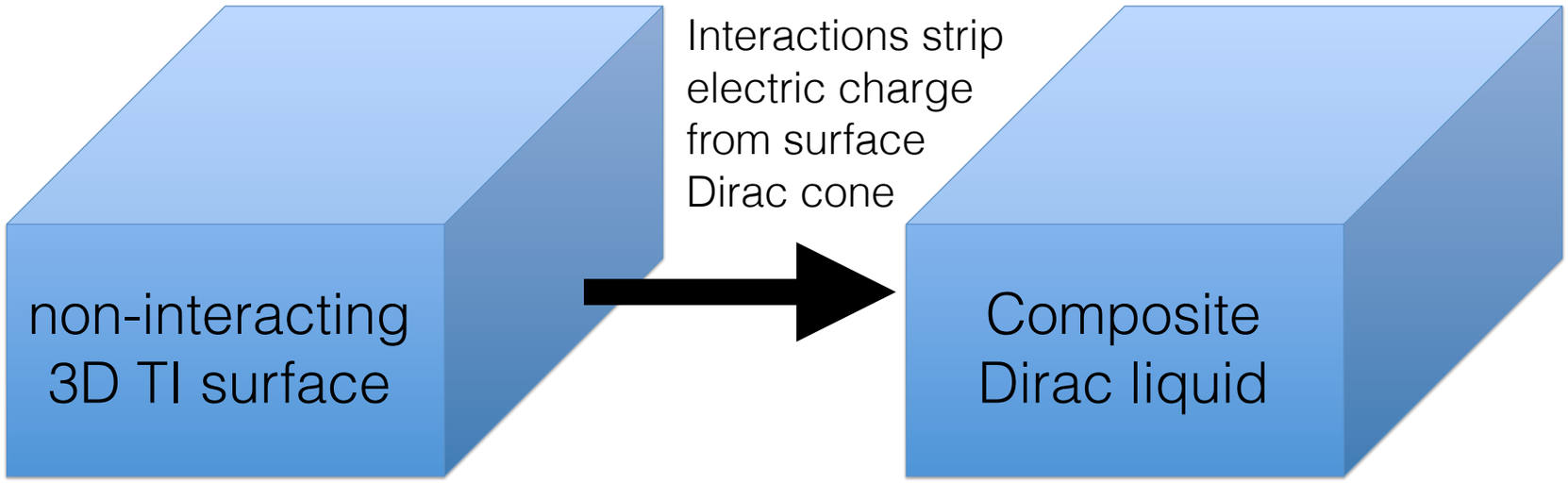

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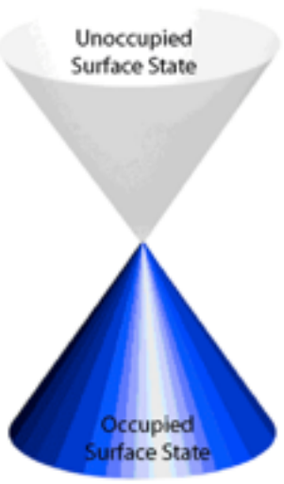
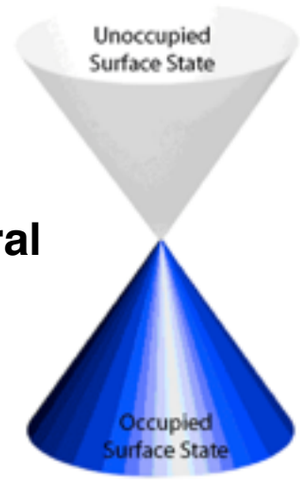


Dirac cone for
emergent **neutral**
fermions!



-Charge sector gapped, so surface is electrical insulator

-Neutral fermions yield “metallic” thermal transport similar to original Dirac cone

-Wild deviation from Weidemann-Franz law!

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non-interacting 3D TI surface

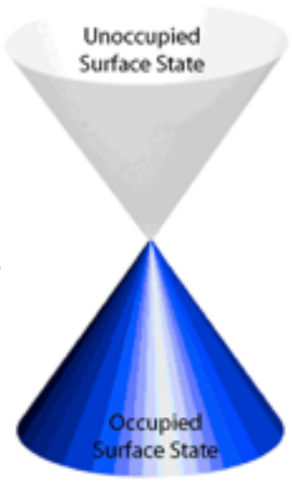
Interactions strip electric charge from surface Dirac cone

Composite Dirac liquid

$\sim$

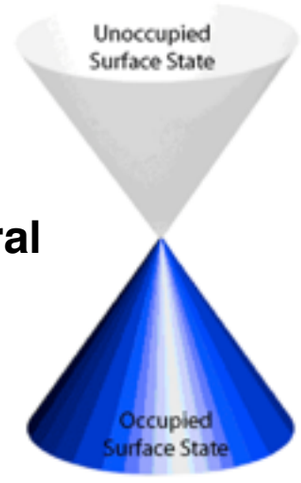
$\odot$ B

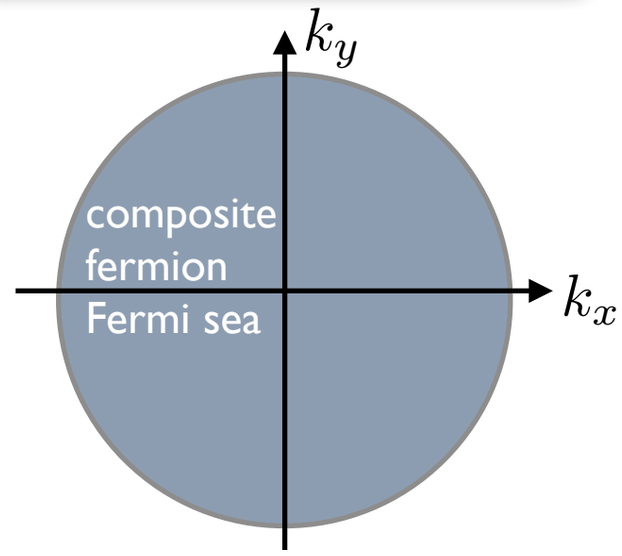
Composite Fermi liquid



electronic Dirac cone

Dirac cone for emergent **neutral fermions!**





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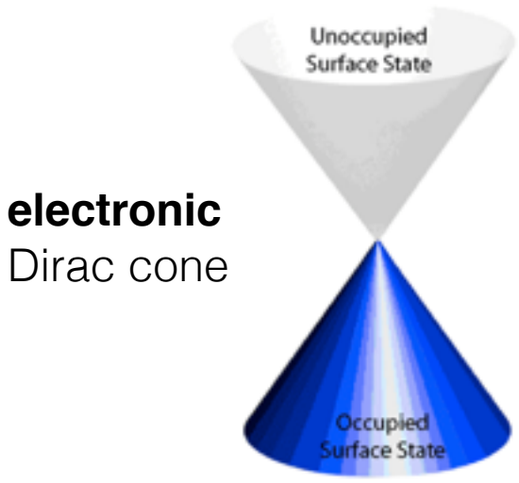

electronic Dirac cone

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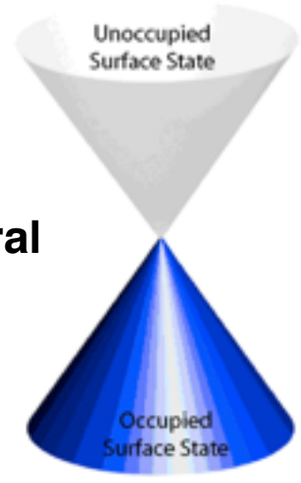
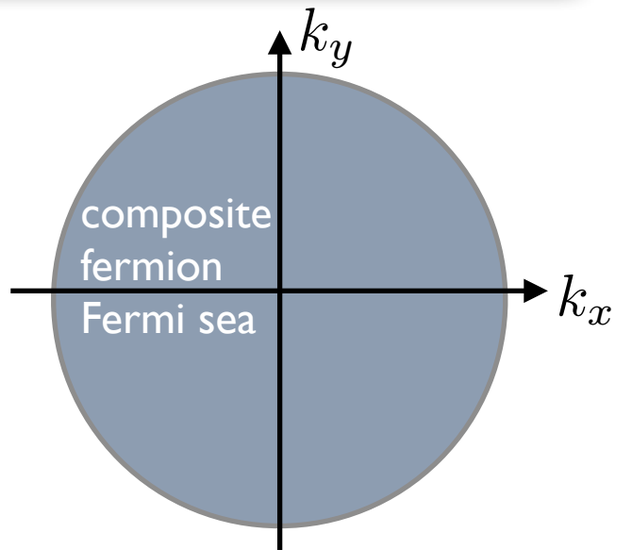


Cooper pair neutral fermions [preserves U(1)]

time-reversal-invariant cousin of Moore-Read (T-Pfaffian)!

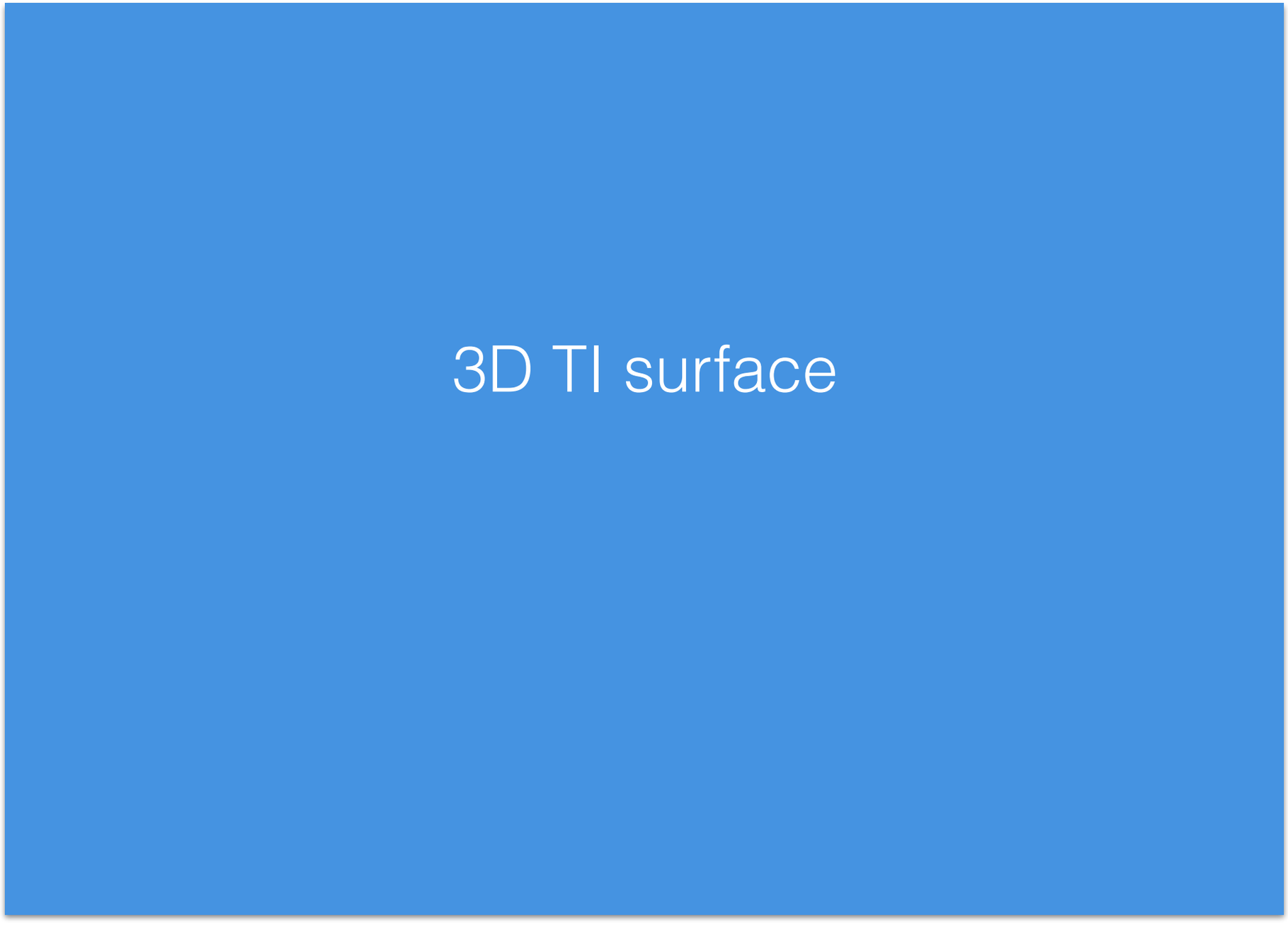


Cooper pair composite fermions

non-Abelian Moore-Read FQH state

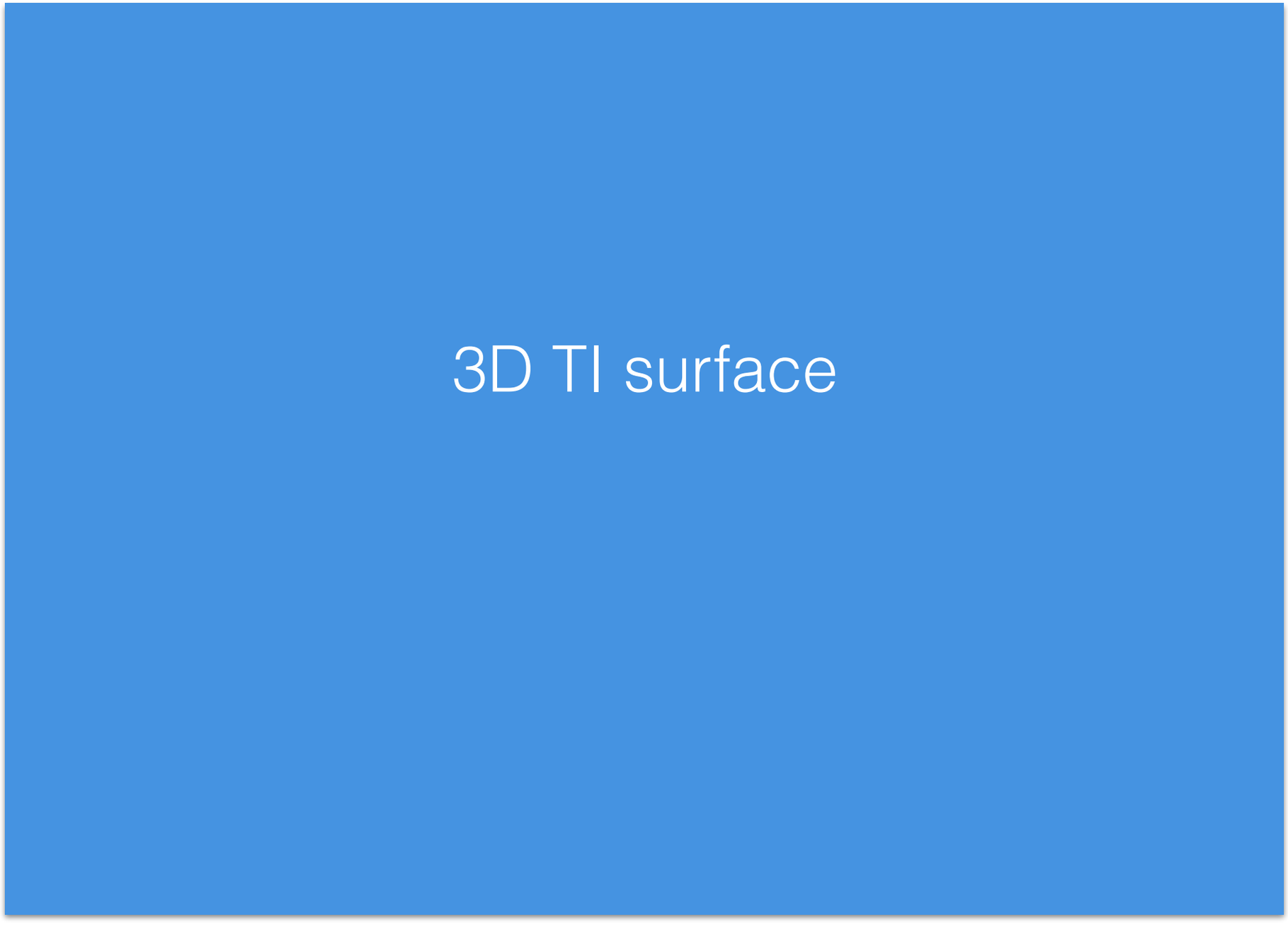
Accessing composite Dirac liquids

In an ideal world: $H_{\mathrm{Dirac}} + H_{\mathrm{interactions}} \Rightarrow$ Composite Dirac liquid



Accessing composite Dirac liquids

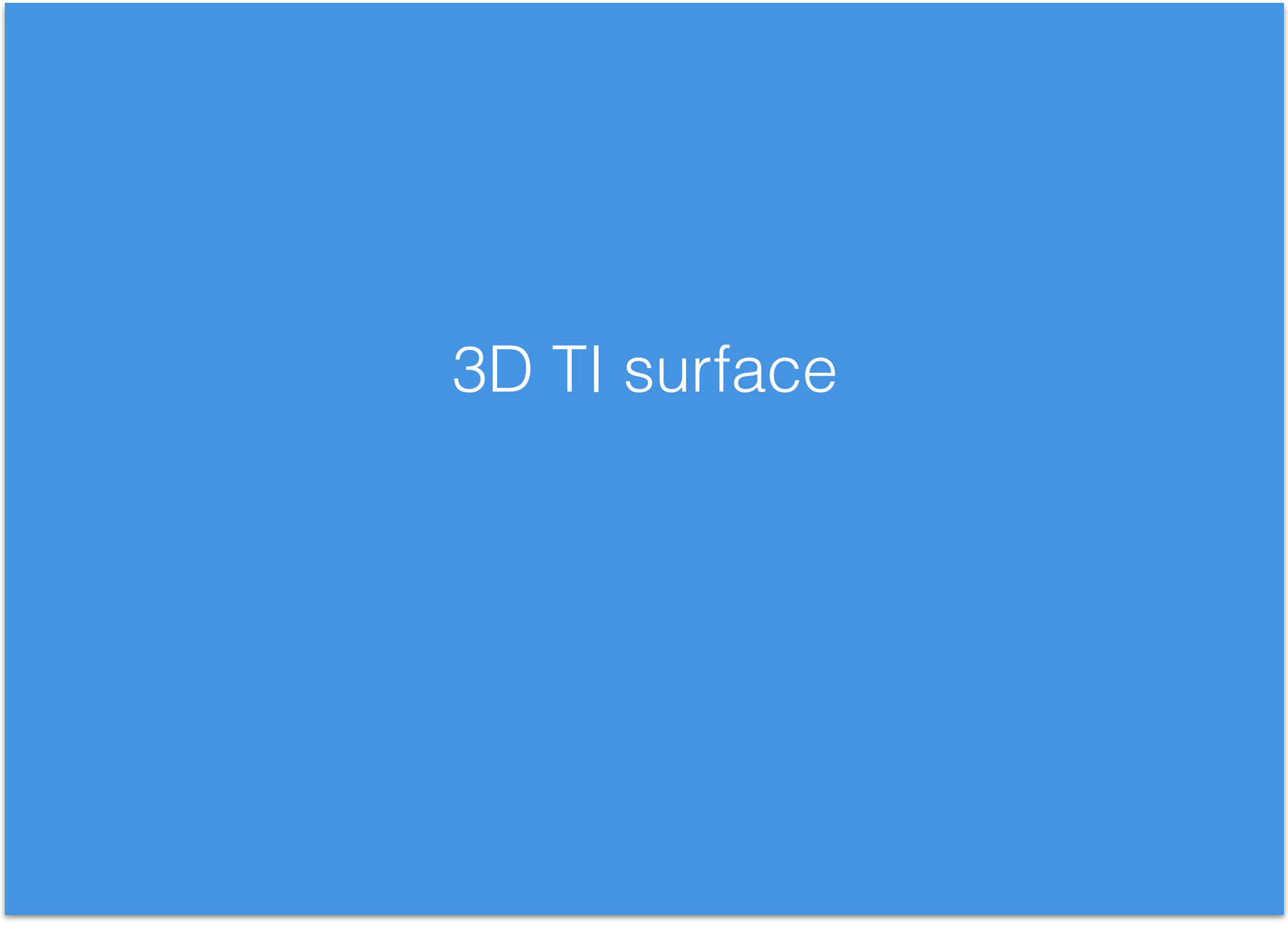
In an ideal world: $H_{\text{Dirac}} + H_{\text{interactions}} \Rightarrow$ Composite Dirac liquid (too hard)



Instead, will “cheat” and follow route with virtues of physical transparency, analytical control.

Accessing composite Dirac liquids

Key technical idea: relax time-reversal to weaker “antiferromagnetic” symmetry
(states *still* impossible in 2D)



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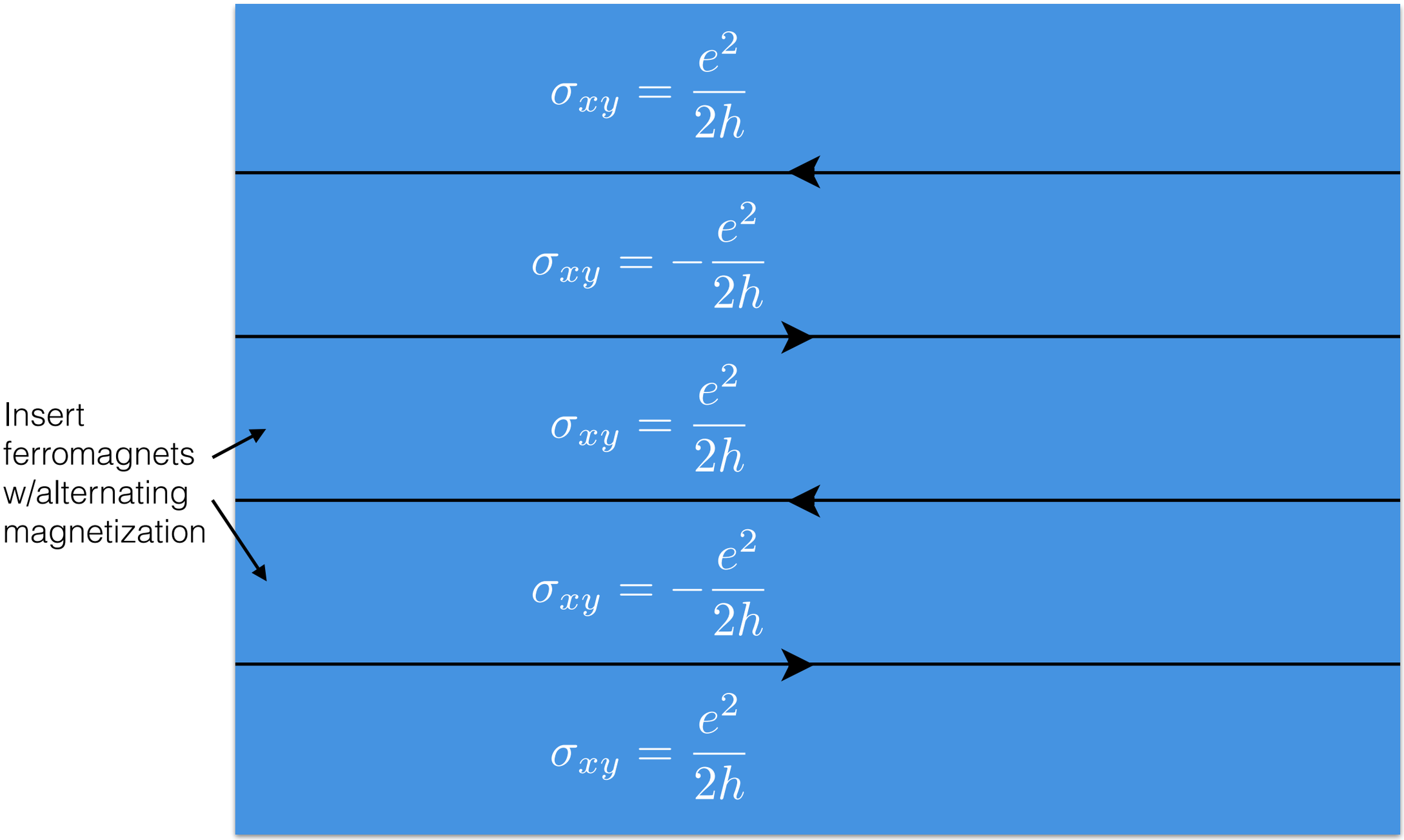

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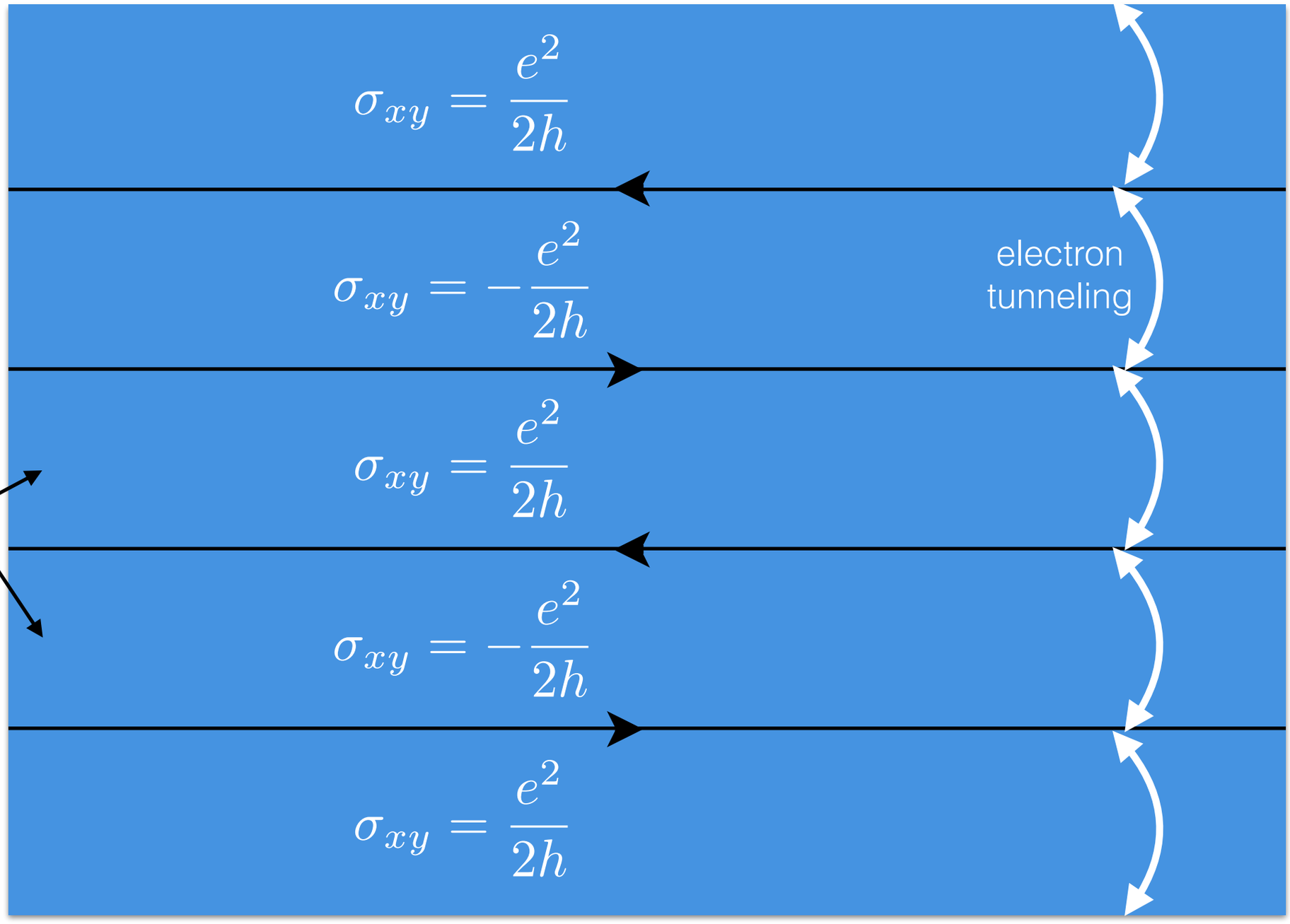

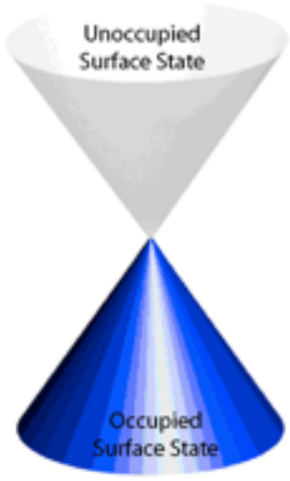

electronic
Dirac cone ✔

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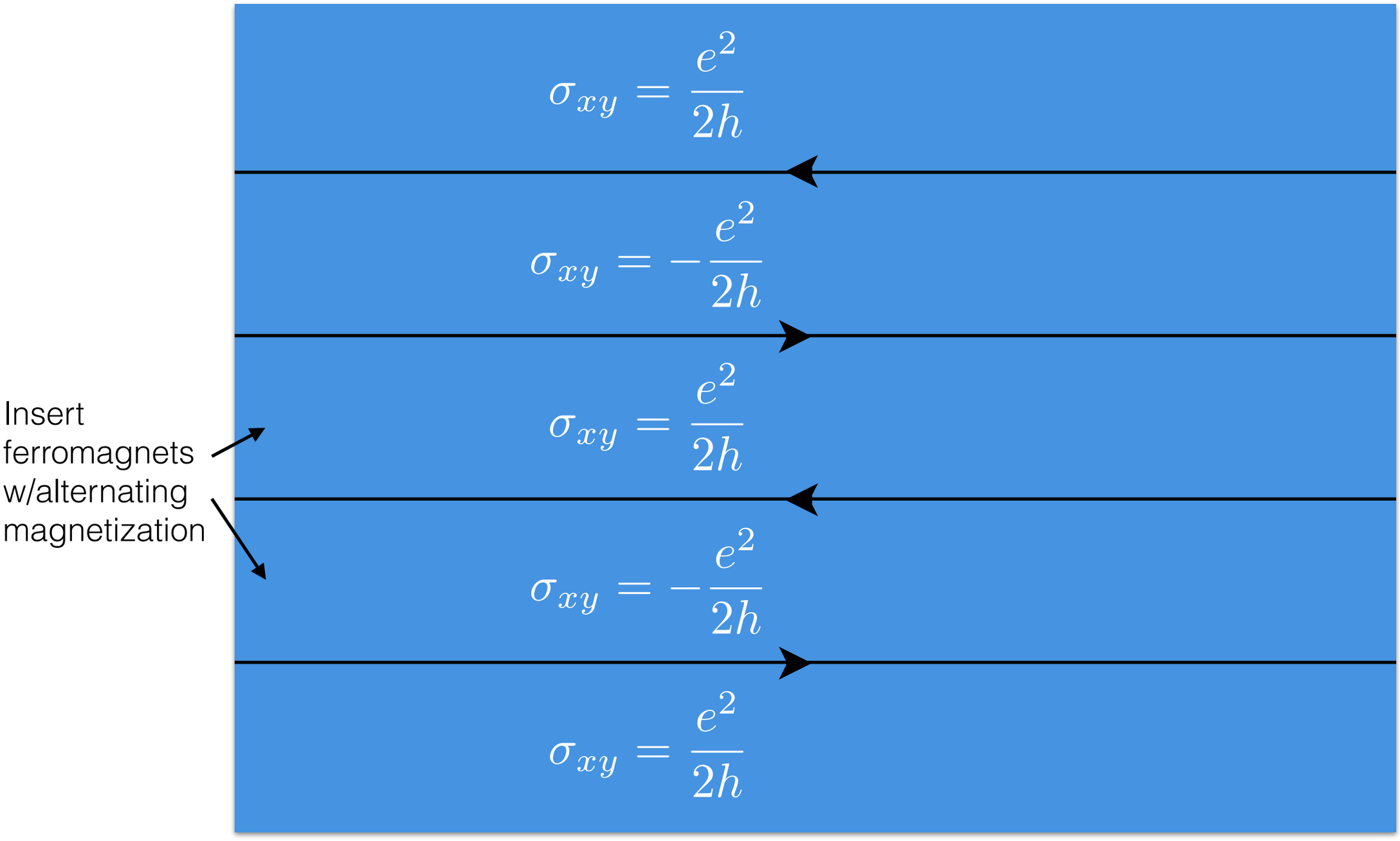

Quasi-1D deformation allows rigorous analytical progress a la **Teo & Kane**.

Accessing composite Dirac liquids

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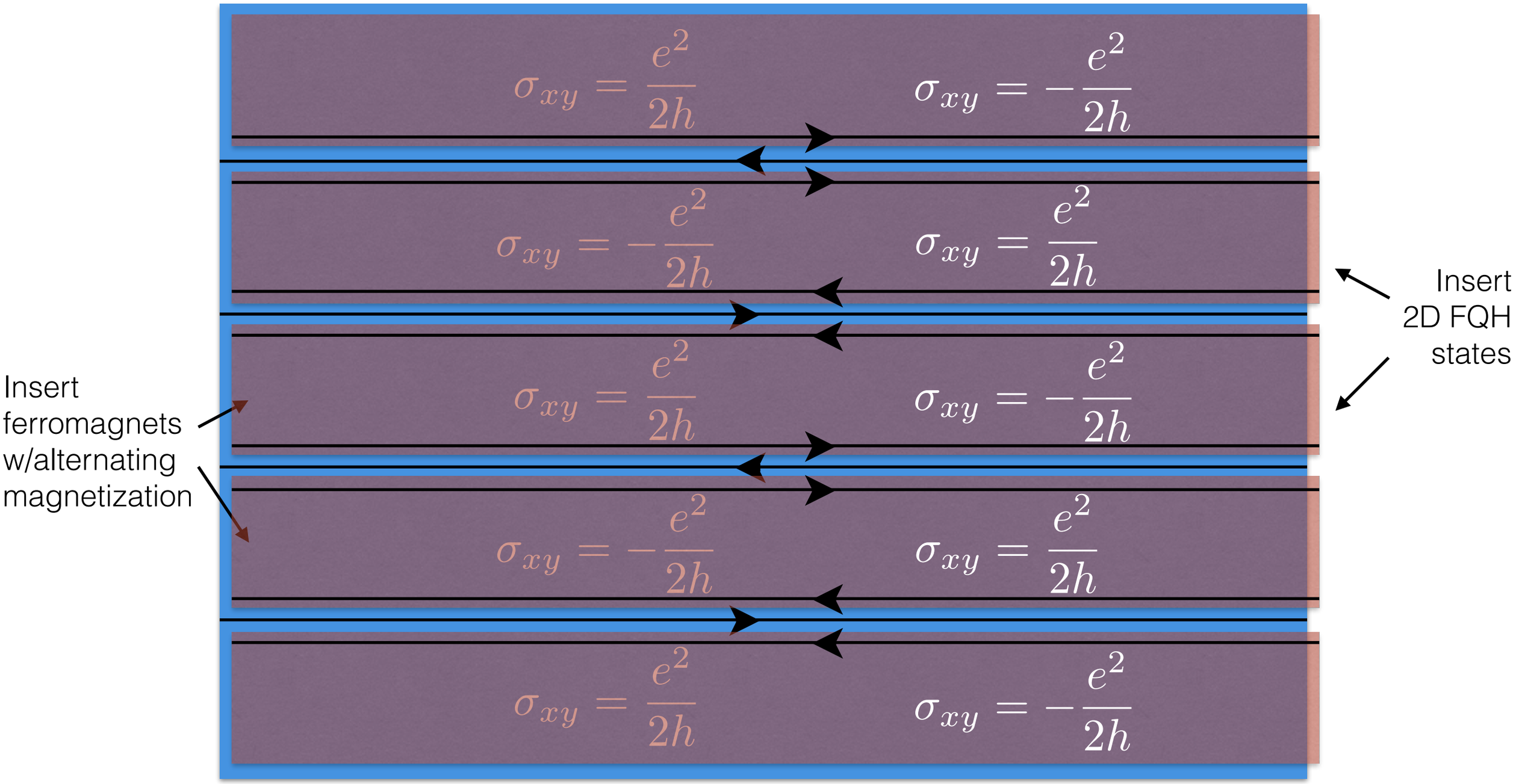

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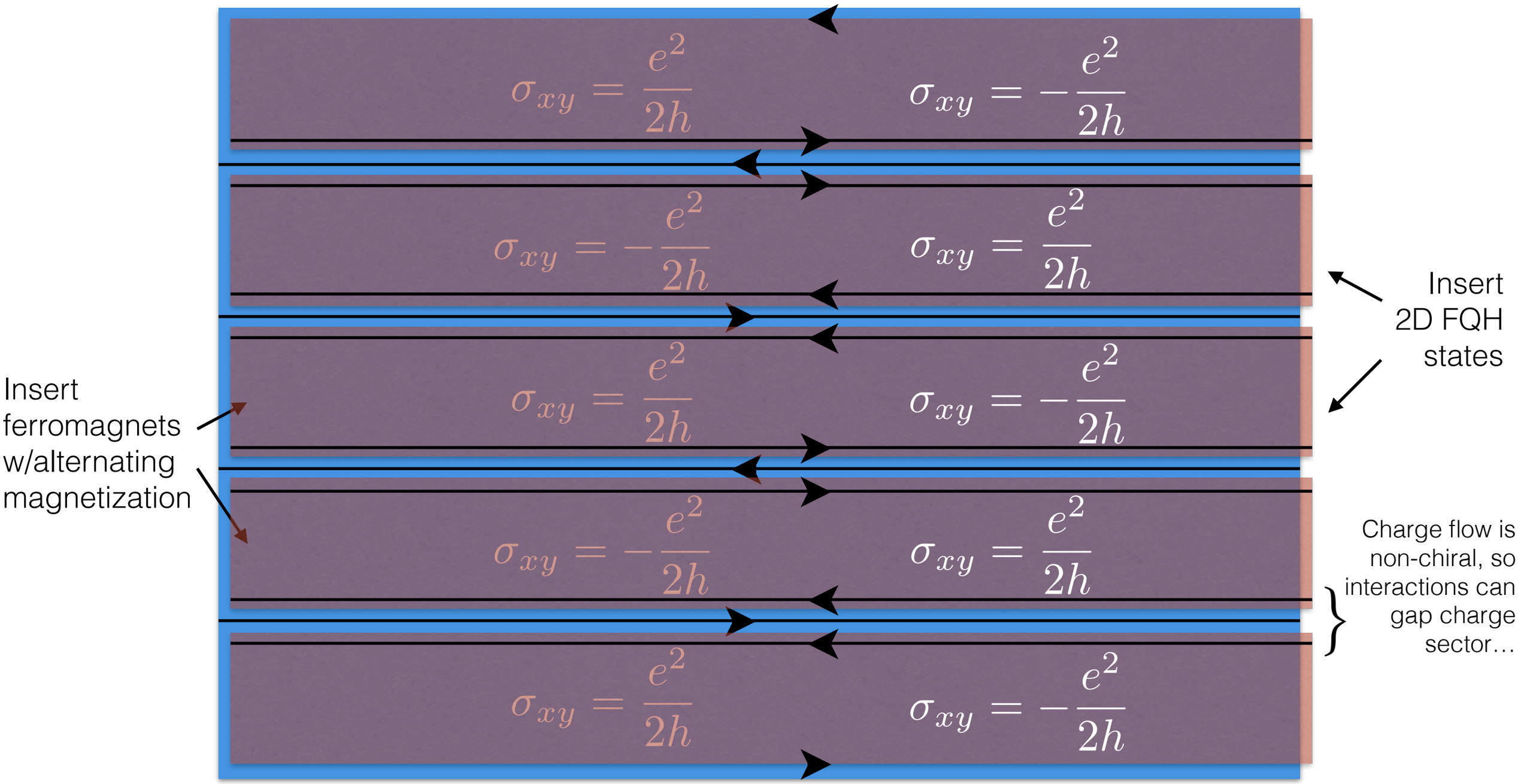

…but heat transport is chiral, so must have neutral modes left over!

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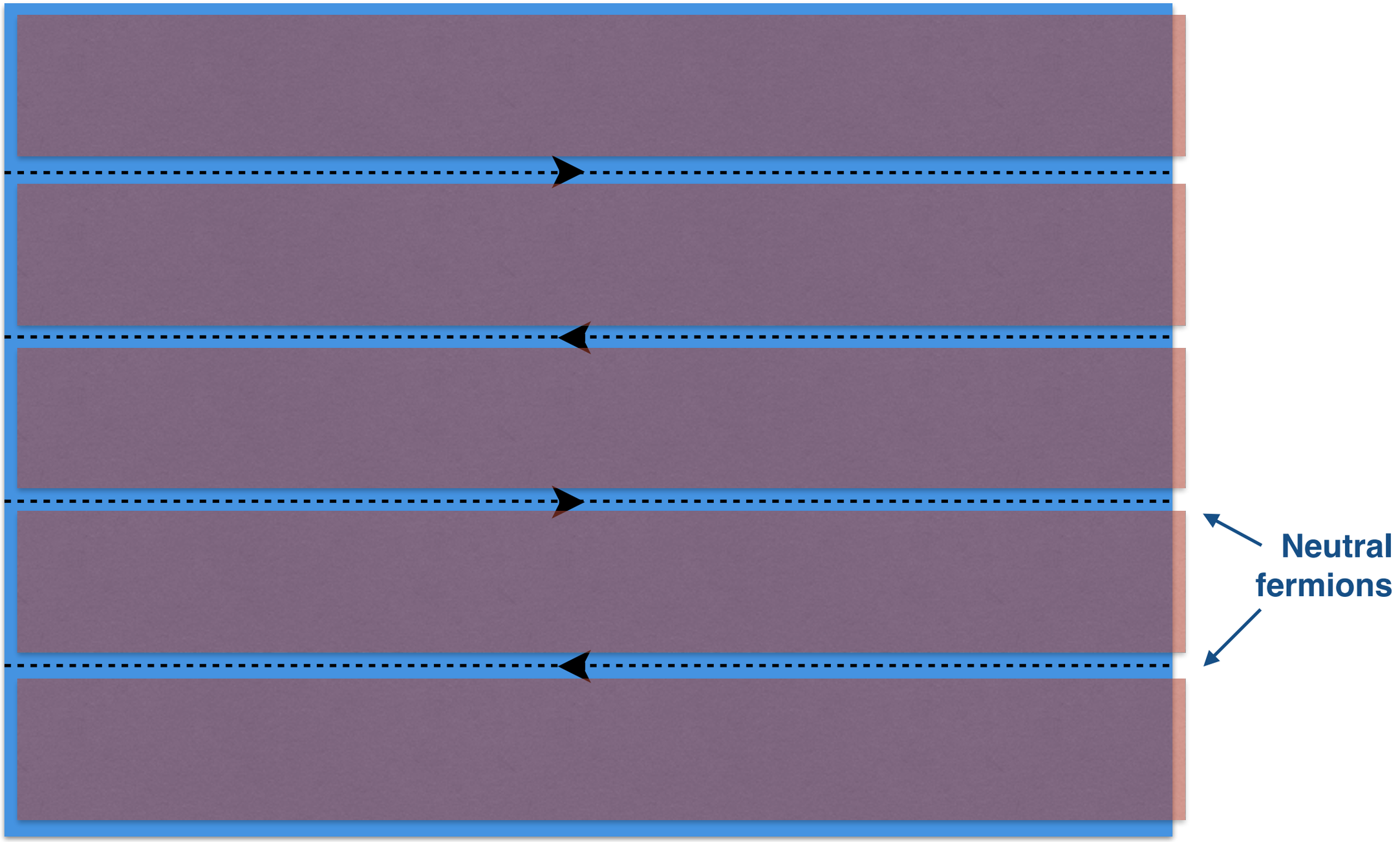

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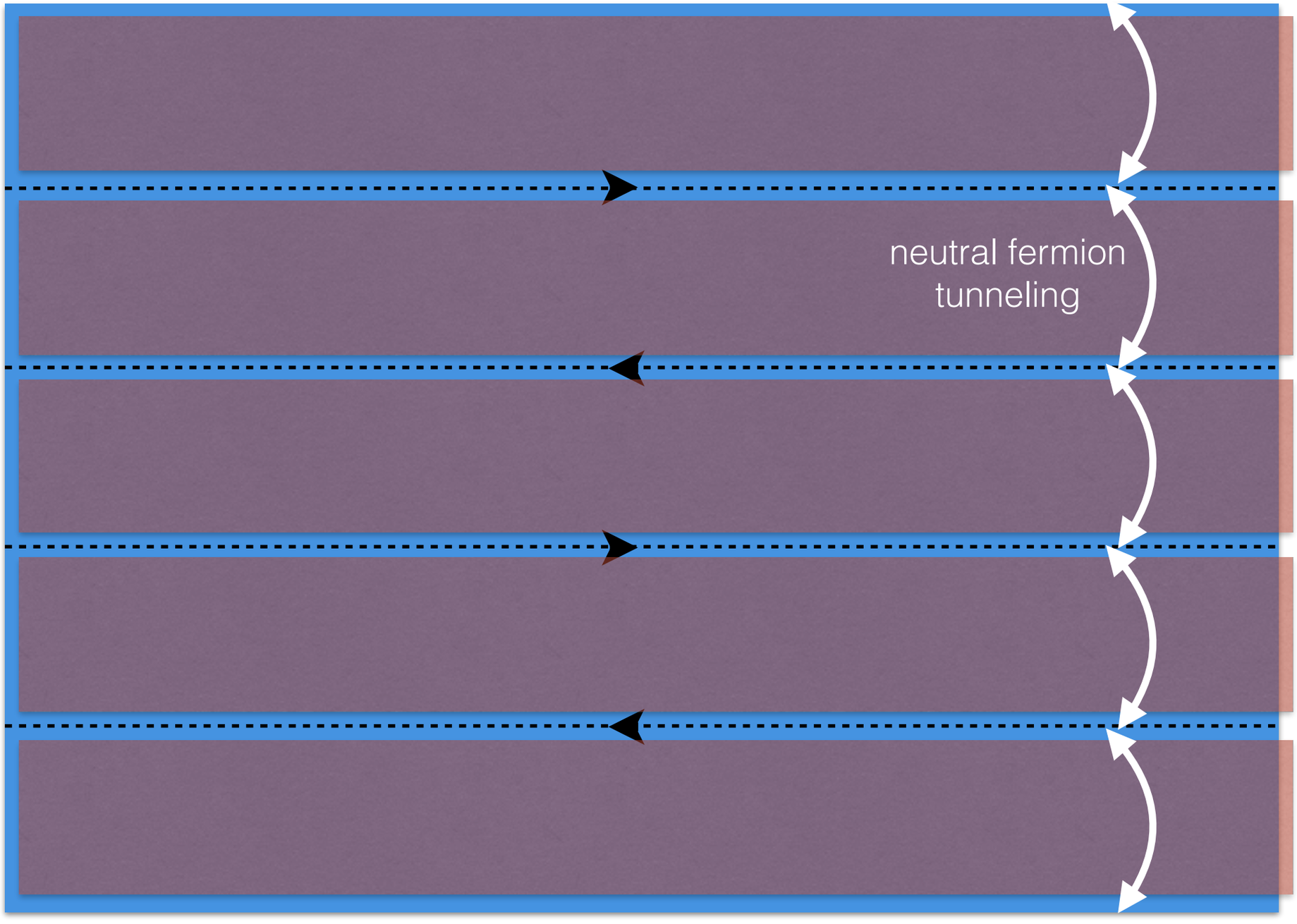
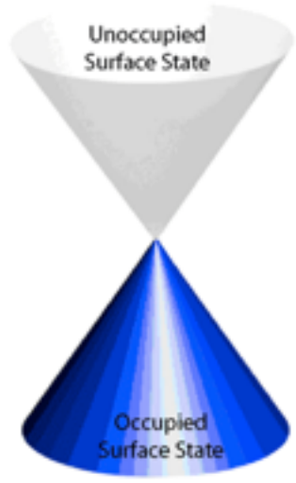
Accessing composite Dirac liquids

Composite Dirac liquid!





neutral Dirac cone

Neutral fermions

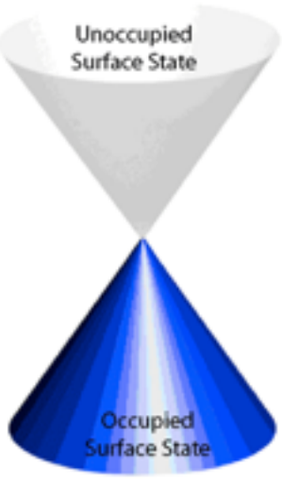
…but heat transport is chiral, so must have neutral modes left over!

Nested Composite Dirac Liquids

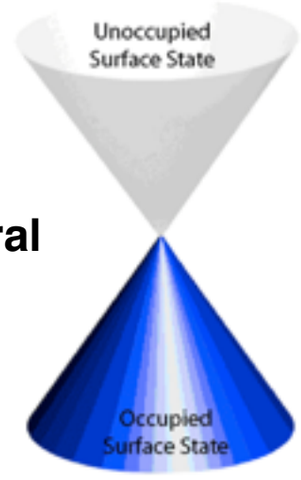
non-interacting 3D TI surface

Interactions strip electric charge from surface Dirac cone

Composite Dirac liquid



electronic Dirac cone



Dirac cone for emergent **neutral fermions!**

Cooper pair neutral fermions [preserves U(1)]

time-reversal-invariant cousin of Moore-Read (T-Pfaffian)

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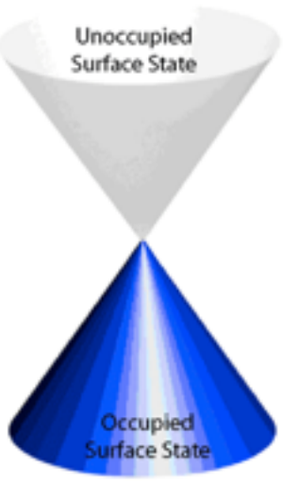
Same interactions, but for neutral fermions

Nested Composite Dirac liquid



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"2nd generation" neutral Dirac cone

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symmetric topological order w/more anyons (Pfaffian-antisemion)

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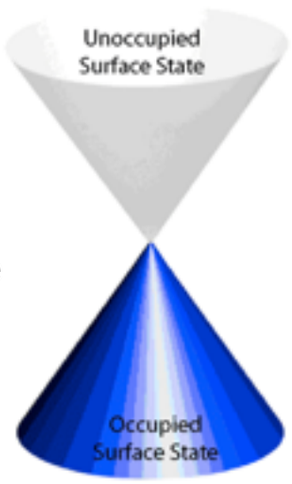
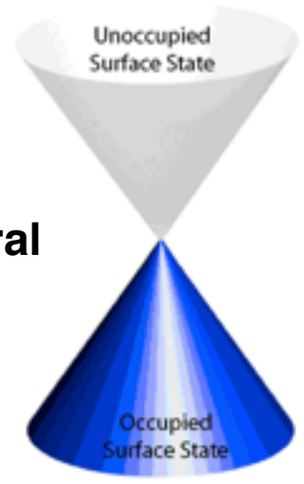


electronic Dirac cone



Dirac cone for emergent **neutral fermions!**

"2nd generation" neutral Dirac cone

Cooper pair neutral fermions [preserves U(1)]

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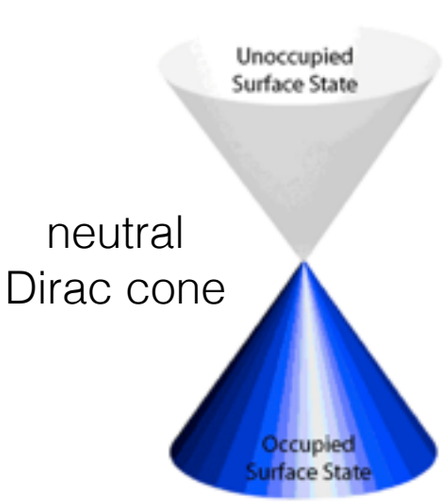
Topological orders captured previously, now in one unified framework!

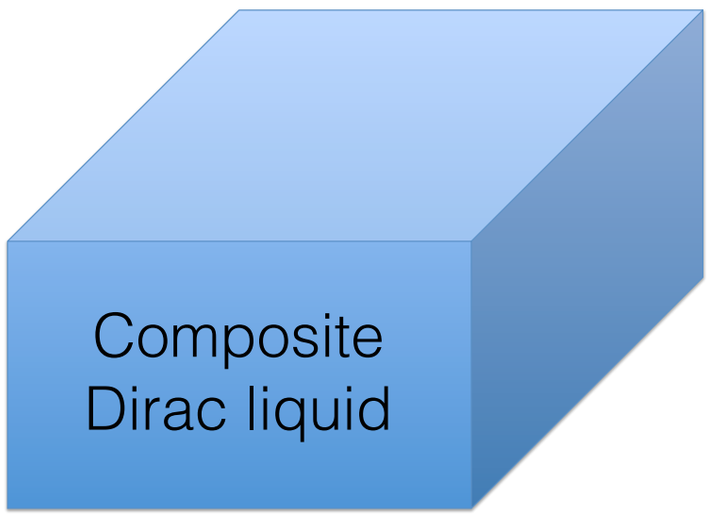
time-reversal-invariant cousin of Moore-Read (T-Pfaffian)

symmetric topological order w/more anyons (Pfaffian-antisemion)

Outlook

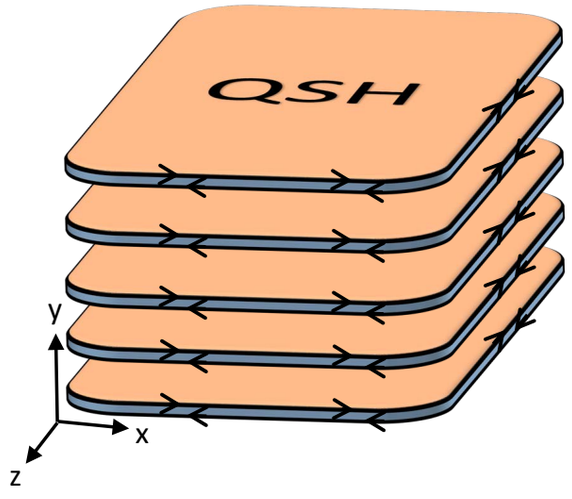
Interplay between interactions, symmetry-protected topological phases rich topic.





Provide unifying view on lots of physics, including quantum Hall; accessible via controlled analytical methods that deal with physical electrons.

Naturally extends to “weak topological insulators”.
(D. Mross, A. Essin, JA, A. Stern, in preparation)



Extension to 3D topological superconductors?

Isotropic implementations?

Quasi-realistic Hamiltonians for such states?